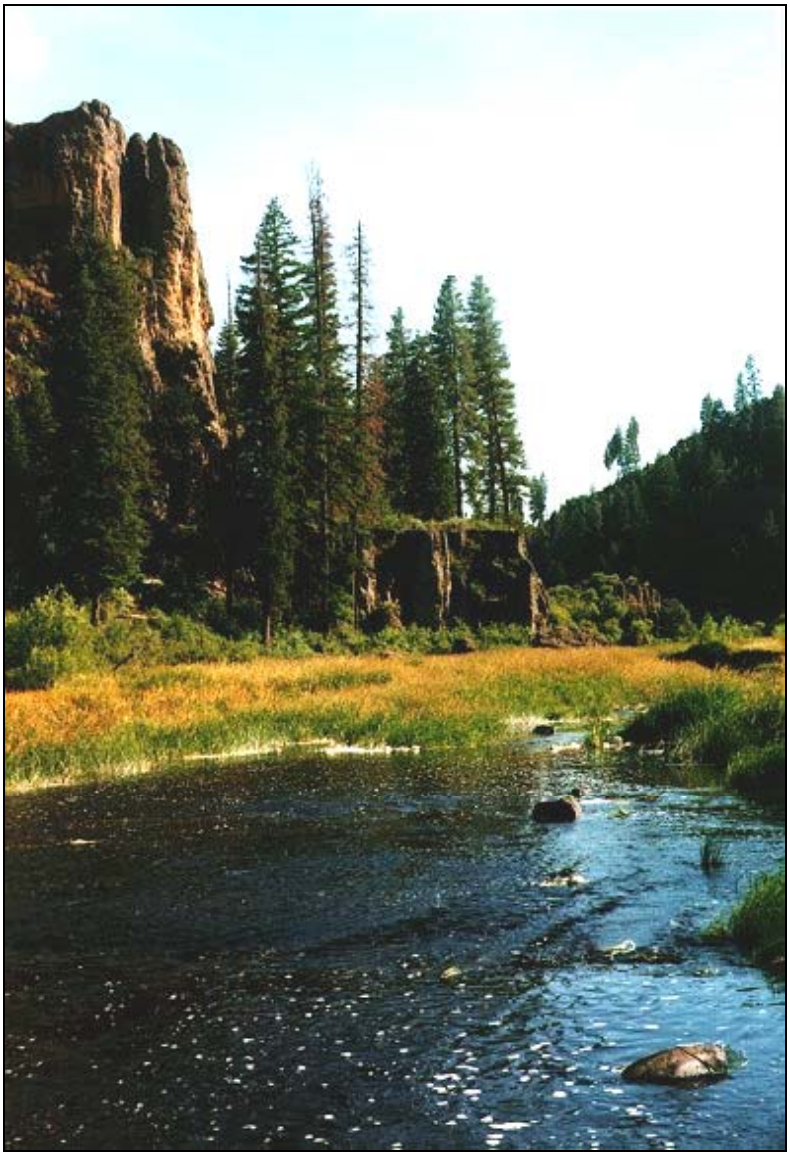
ATTACHMENT 1
UPPER KLAMTH LAKE DRAINAGE TMDL

UPPER KLAMATH LAKE DRAINAGE STREAM TEMPERATURE ANALYSIS

VEGETATION, HYDROLOGY AND MORPHOLOGY



THIS DOCUMENT WILL BE USED IN THE UPPER KLAMATH BASIN TEMPERATURE TMDL

PREPARED BY OREGON DEQ
MAY, 2002

DEQ

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UPPER KLAMATH LAKE DRAINAGE STREAM TEMPERATURE ANALYSIS

VEGETATION, HYDROLOGY AND MORPHOLOGY

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UPPER KLAMATH LAKE DRAINAGE STREAM TEMPERATURE ANALYSIS

VEGETATION, HYDROLOGY AND MORPHOLOGY

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CHAPTER 1. INTRODUCTION

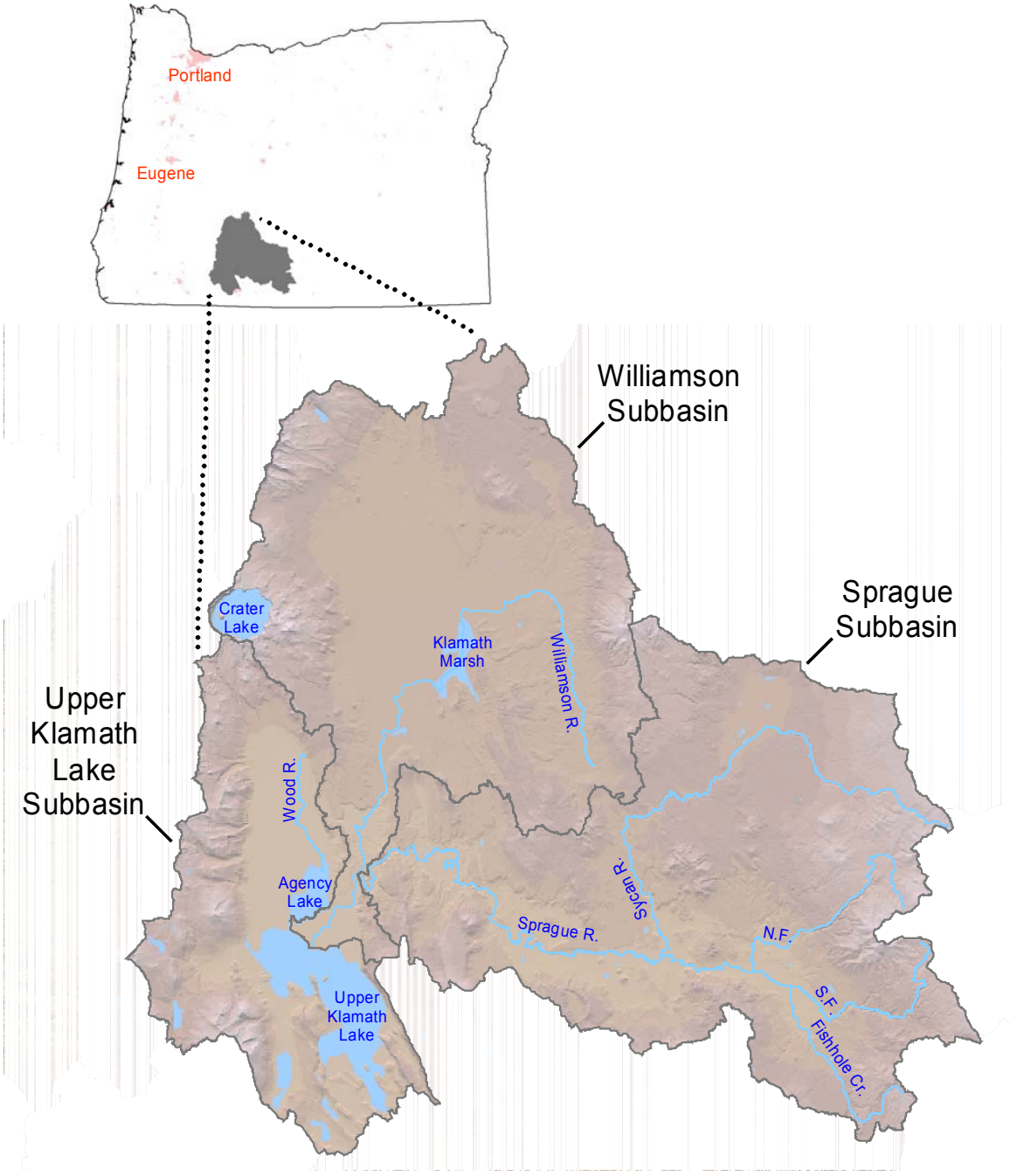


Figure 1-1. *The Upper Klamath Lake drainage includes three 4th field hydrologic units: Williamson, Sprague and Upper Klamath Lake Subbasins.*

Terms Used in this Chapter

Advection - The rate of transportation of suspended/dissolved substances and heat caused by flow velocity in the water column is called advection. It is a function of stream gradient, channel dimensions and channel roughness.

Anthropogenic – Caused by or originating from humans

Background – All non-anthropogenic sources of pollutants. In cases the Department is unable to distinguish background and anthropogenic sources of pollutants, the pollutants are considered as background in the analysis.

Dispersion - Diffusion in flowing open channels occurs at a high rate due to turbulent mixing. Water flows are turbulent because cross-sectional flow velocities are variable, with slower velocities near the channel boundaries caused by friction. Dispersion refers to turbulent diffusion and is often much greater than molecular diffusion.

Heat - Energy associated with the random motion of molecules.

Heat Flux – Rate of heat transfer per unit surface area.

Heat Transfer - Processes that change the heat of a body. Can occur through direct contact, radiation, evaporation and other related processes.

Hydrologic Unit - A USGS classification of drainage areas: watershed (5^{th} Field), subbasin (4^{th} Field) and basin (3^{th} Field).

Hyporheic Zone - The saturated sediments and interstitial spaces beneath streams, receiving water from both above and below ground.

Load Allocation – The portion of pollutants allowed in a total maximum daily load for anthropogenic and background nonpoint sources.

Mass Transfer - Processes that change the mass of a body. In open channel systems it can occur through advection, dispersion and mixing with surface and subsurface waters.

Nonpoint Sources – Pollutants that originates from dispersed locations such as, but not limited to, agricultural land uses, forestry and background sources.

Point Sources – Pollution that originates from a fixed location such as industrial waste.

Pollutant – Solid waste, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, and industrial, municipal, and agricultural waste discharge into water.

Pollution – Alteration of physical, chemical or biological properties of any waters of the state which tends to, either by itself or in connection with any other substance, create a public nuisance or which will or tends to render such waters harmful, detrimental or injurious to beneficial uses.

Solar Zenith - For any given day, the angle at which the sun is at the highest position in the sky.

Source – Any process, practice or activity that causes pollution or induces pollutants into a waterbody.

Thermodynamic - The physics that relate to the processes of heat transfer and mechanical processes associated with heat.

Total Maximum Daily Load – A plan developed under the Clean Water Act that is designed to reduce pollution to levels that meet water quality standards.

Unit Volume - A standardized volume measurement.

Waste Load Allocation - The portion of pollutants allowed in a total maximum daily load for point source

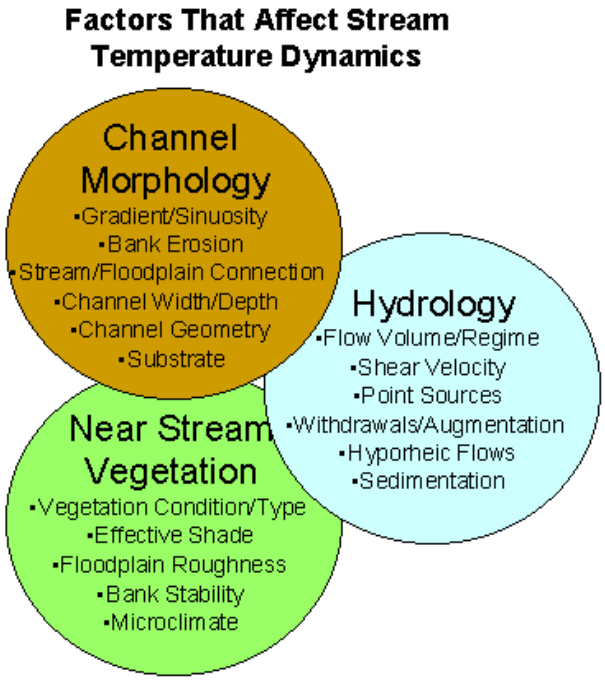
1.1 Scale

The lands that drain to Upper Klamath Lake occupy 3,774 square miles (2,415,046 acres) in south-central Oregon, east of the Cascade Mountain Range divide. This drainage includes three 4th field hydrologic unit subbasins: Upper Klamath Lake (18010203), Williamson (18010201) and Sprague (18010202). While the stream temperature TMDL considers all surface waters within the Upper Klamath Lake Drainage, this analysis largely focuses on the largest water bodies and those that are most thermally impaired, namely: Williamson River, Sprague River, North Fork Sprague River, South Fork Sprague River, Fishhole Creek and Sycan River.

1.2 Scope

Parameters that affect stream temperature can be grouped as near stream land cover, channel morphology and hydrology. Many of these stream parameters are interrelated (i.e., the condition of one may impact one or more of the other parameters). These parameters affect stream **heat transfer processes** and stream **mass transfer processes** to varying degrees. The analytical techniques employed to develop the Upper Klamath Lake Drainage Temperature TMDL are designed to include all of the parameters that affect stream temperature provided that available data and methodologies allow accurate quantification.

Stream temperature dynamics are complicated when these three parameters (i.e. near stream land cover, channel morphology and hydrology) are evaluated on a watershed or subbasin scale. Many parameters exhibit considerable spatial variability. For example, channel width measurements can vary greatly over small stream lengths. Some parameters can have a diurnal and seasonal temporal component as well as spatial variability. The current analytical approaches developed for stream temperature assessment consider all of these parameters and rely on ground level and remotely sensed spatial data. To understand temperature on a landscape scale is a difficult and often resource intensive task. General analytical techniques employed in this effort are statistical and deterministic modeling of hydrologic and thermal processes.



Stated Purpose:

The overriding intent of this analytical effort is to improve the understanding of the Upper Klamath Lake drainage stream temperature dynamics in both spatial and temporal scales.

Acknowledged Limitations:

It should be acknowledged that there are limitations to this effort:

- The scale of this effort is large with obvious challenges in capturing spatial variability in stream and landscape data. Available spatial data sets for land cover and channel morphology are coarse, while derived data sets are limited to aerial photo resolution, rectification limitations and human error.
- Data are insufficient to describe high-resolution instream flow conditions making validation of derived mass balances difficult.
- The water quality issues are complex and interrelated. The state of the science is still evolving in the context of comprehensive landscape scaled water quality analysis. For example, quantification techniques for microclimates that occur in near stream areas are not developed and available to this effort. Regardless, recent studies indicate that forested microclimates play an important, yet variable, role in moderating air temperature, humidity fluctuations and wind speeds.
- Quantification techniques for estimating potential subsurface inflows/returns and behavior within substrate are not employed in this analysis. While analytical techniques exist for describing subsurface/stream interactions, it is beyond the scope of this effort with regard to data availability, technical rigor and resource allocations.
- Land use patterns vary through the drainage from heavily impacted areas to areas with little human impacts. However, it is extremely difficult to find large areas without some level of either current or past human impacts. The development of potential conditions that estimate stream conditions when human influences are minimized is statistically derived and based on stated assumptions within this document. Limitations to stated assumptions are presented where appropriate. It should be acknowledged that as better information is developed these assumptions will be refined.

While these assumptions outline potential areas of weakness in the methodology used in the stream temperature analysis, the Oregon Department of Environmental Quality has undertaken a comprehensive approach. All of the important stream parameters that can be accurately quantified are included in this analysis. In the context of understanding of stream temperature dynamics in the Upper Klamath Lake drainage, these areas of limitations should be the focus for future study. **ODEQ acknowledges the limitations stated above in accordance with the scientific method and it also recognizes that this analytical effort provides a rigorous, complete, statistically valid and advanced treatment of stream temperature dynamics**.

1.3 Overview of Stream Heating Processes

Stream temperature dynamics are complex. Changes in rates of heat transfer can vary considerably across relatively small spatial and temporal scales. In quantifying and understanding stream heat and mass transfer processes, the challenge is not represented in theoretical conceptions of thermodynamics and relations to flowing water. Thermodynamics is a well-established academic discipline that offers a scientifically tested methodology for understanding stream temperature. In fact, the methodology used to evaluate stream temperature is quite simple when compared to other thermodynamic applications that have become common technological necessities to the American way of life (i.e. a car radiators, cooling towers, solar thermal panels, insulation, etc.). Instead, the true challenge in

understanding stream temperature materializes with the recognition that thermally significant heat and mass transfer processes occur in very fine spatial and temporal scales. Tremendous spatial variability occurs across a watershed, and is compounded by adding a temporal component. At any stream reach, thermal processes constantly change throughout the day, month and year. Stream temperatures are a result of a multitude of heat transfer and mass transfer process. The conceptual and analytical challenge is to develop a framework that captures these forms of variability to the best possible extent.

Water temperature change (ΔT_w) is a function of the heat transfer in a discrete volume and may be described in terms of changes in heat per unit volume. It is then possible to discuss stream temperature change as a function of two variables: heat and mass transfer.

Water Temperature Change as a Function of Heat Exchange per Unit Volume,

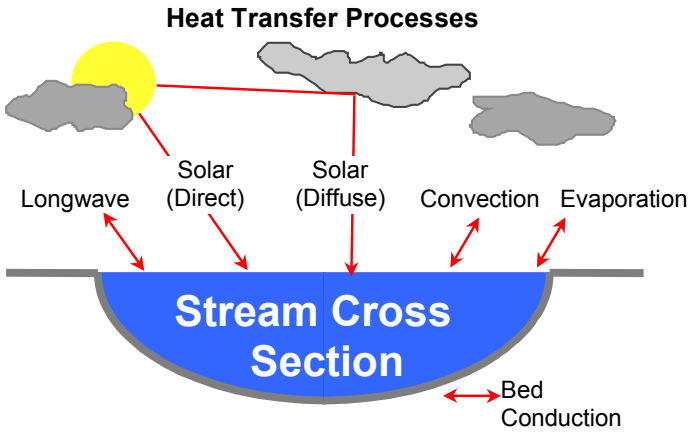
$$\Delta T_w \propto \frac{\Delta Heat}{Volume}$$

1. **Heat transfer** relates to processes that change heat in a defined water volume. There are several thermodynamic pathways that can introduce or remove heat from a stream. For any given stream reach heat exchange is closely related to the season, time of day and the surrounding environment and the stream characteristics. Heat transfer processes can be dynamic and change over relatively small distances and time periods. Several heat transfer processes can be affected by human activities. These pathways are discussed below in **Section 1.3.1 Heat Transfer Processes**.

2. **Mass transfer** relates to transport of flow volume downstream, instream mixing and the introduction or removal of water from a stream. For instance, flow from a tributary will cause a temperature change if the temperature is different from the receiving water. Mass transfer occurs commonly in stream systems as a result of advection, dispersion, groundwater exchange, hyporheic flows, surface water exchange and other human related activities that alter stream flow volume. Mass transfer processes are discussed in **Section 1.3.2 Mass Transfer Processes**.

1.3.1 Heat Transfer Processes

Stream heating processes follow two cycles: a seasonal cycle and a diurnal cycle. In the Pacific Northwest, the seasonal stream heating cycle experiences a maximum positive flux during summer months (July and August) while the minimum seasonal stream heating periods occur in the winter months (December and January). The diurnal net heating cycle experiences a daily maximum at or near midday. This maximum usually corresponds to the solar zenith. The daily minimum rate of stream heating usually occurs during the late night or the early morning. It should be noted, however, that meteorological conditions are variable. Cloud cover and precipitation, humidity and wind seriously alter the heat transfer pathways between the stream and its environment.



The heat transfer processes that control stream temperature include solar radiation, longwave radiation, convection, evaporation, and bed conduction. All other processes are capable of both introducing and removing heat from a stream, with the exception of solar radiation, which only delivers heat energy. These thermal processes occur simultaneously and result in an overall rate of heat exchange with a stream.

When a stream surface is exposed to midday solar radiation, large quantities of heat will be delivered to the stream system (Brown 1969, Beschta et al. 1987). Low levels of stream shade allows solar radiation to become a dominant stream heating transfer process. This holds true even when accounting for surface reflection and the absorption properties of water outside the visible spectrum. As would be expected maximum heat transfer rates occur when a stream is exposed to midday solar radiation.

Longwave radiation, also referred to as thermal radiation, is a source of both heating and cooling. Longwave radiation heat is derived from the atmosphere and vegetation along stream banks and is a source of heat when received by the stream surface. Water readily absorbs the thermal spectral wavelength. Longwave radiation is also emitted from the stream surface, and thus, has a cooling influence. Thermal radiation emitted from the stream is called back radiation and can be accurately measured from aerial remote sensing equipment. The net transfer of heat via longwave radiation usually balances so that the amount of heat entering is similar to the rate of heat leaving the stream (Beschta and Weatherred, 1984; Boyd, 1996). The overall net heat transfer rate from longwave radiation (i.e. the sum from the atmosphere, surrounding land cover and back radiation from the stream) is small relative to other thermal processes.

Evaporation occurs in response to internal energy of the stream (molecular motion) that randomly expels water molecules into the overlying air mass. Evaporation is the most effective method of dissipating heat from water. This is the preferred cooling mechanism employed by the human body via perspiration. As stream temperatures increase, so does the rate of evaporation. Air movement (wind) and low vapor pressures and relative humidity increase the rate of evaporation and accelerate stream cooling. Evaporation is the primary mechanism for stream cooling.

Condensation is the opposite of evaporation. When the air temperature reaches the dew point, the air mass at the stream surface interface becomes saturated and triggers a phase change of water vapor into liquid. Condensation represents a heating process, but occurs during limited portions of the day if at all (usually during early morning periods when nighttime temperatures are cool). Condensation is a minor component relative to other the heat transfer processes.

Convection transfers heat between the stream and the air via molecular and turbulent conduction. Heat is transferred in the direction of warmer to cooler. Air can have a warming influence on the stream when the stream is cooler. The opposite is also true. The amount of convective heat

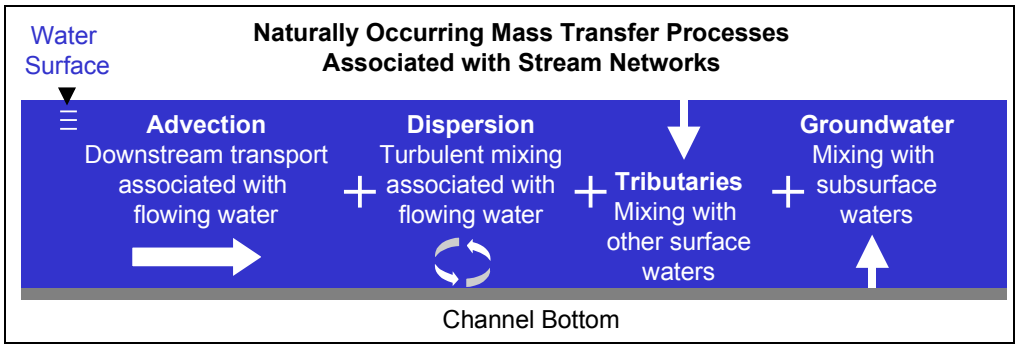
transfer between the stream and air is low. Air has a low conductance relative to water and simply cannot conduct heat efficiently. An easy way to conceptualize the conductance between water and air is to compare the body's perception of temperature when both water and air are at the same temperature. Human exposure to air at 60°F is possible for long periods, while exposure to 60°F water is fatal in a matter of two hours. Air is a poor conductor of heat. Nevertheless, this should not be interpreted to mean that air temperatures do not affect stream temperature. Air temperatures play a complex role in stream heating processes affecting vapor pressure gradients, relative humidity and atmospheric thermal radiation levels. However, air temperatures can only impart heat to a stream very slowly via conduction.

Depending on streambed composition, solar radiation may warm the streambed. Larger substrate dominated streambeds and/or shallow streams may allow the bed to differentially heat and then conduct heat to the stream as long as the bed is warmer than the stream. Bed conduction of heat to the water column may cause maximum stream temperatures to occur later in the day, possibly into the evening hours.

Heat associated with physical processes such as friction and compression is a negligible source and is not included in this analysis.

1.3.2 Mass Transfer Processes

Mass transfer processes refer to the downstream transport and mixing of water throughout a stream system. The downstream transport of dissolved/suspended substances and heat associated with flowing water is called advection. Dispersion results from turbulent diffusion that mixes the water column. Due to dispersion, flowing water is usually well mixed vertically. Stream water mixing with inflows from surface tributaries and subsurface groundwater sources also redistributes heat within the stream system. These processes (advection, dispersion and mixing of surface and subsurface waters) redistribute the heat of a stream system via mass transfer.

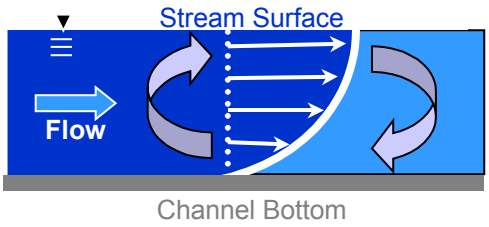


Heat that is transported by river flow is referred to as advected heat. It follows that advection can only occur in the downstream direction. No heat energy is lost or gained by the system during advection, assuming the heat from mechanical processes such as friction and compression is negligible. Advection is simply the rate at which water and heat is transferred downstream.

Dispersion refers to the mixing caused by turbulent diffusion. In natural stream systems flows are often vertically mixed due to turbulent diffusion of water molecules. Turbulent flows result from a variable flow velocity profile, with lower velocities occurring near the boundaries of the channel (i.e. channel bottom and stream banks). Higher velocities occur farthest away from channel boundaries, commonly at the top of the water column. The velocity profile results from the friction between the flowing water and the rough surfaces of the channel. Since water is flowing at different rates through the channel cross-section, turbulence is created, and vertical mixing results. Dispersion mixes water molecules at a much higher rate than molecular diffusion. Turbulent diffusion can be calculated as a function of stream dimensions, channel roughness and average flow velocity. Dispersion occurs in both the upstream and downstream directions.

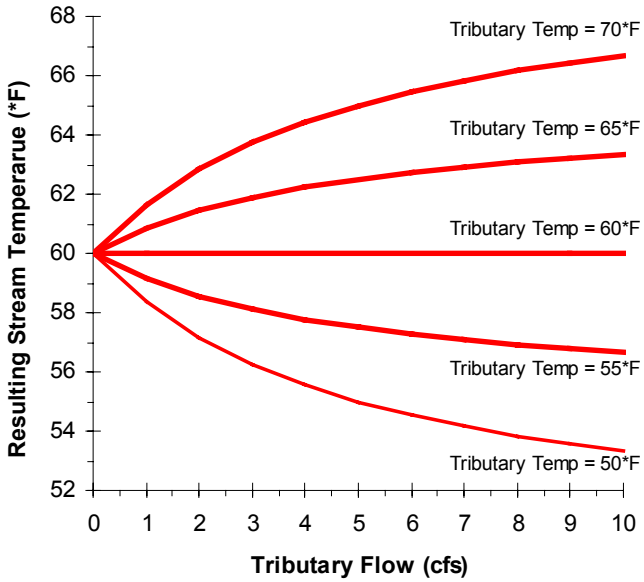
Dispersion refers to mixing from turbulent flow.

Dispersion results from a vertical velocity profile. Velocity varies as a function of channel depth. Slower velocities occur at the bottom of the water column. Faster velocities occur at the top of the water column. The vertical gradient in flow velocity causes a tumbling motion of water.



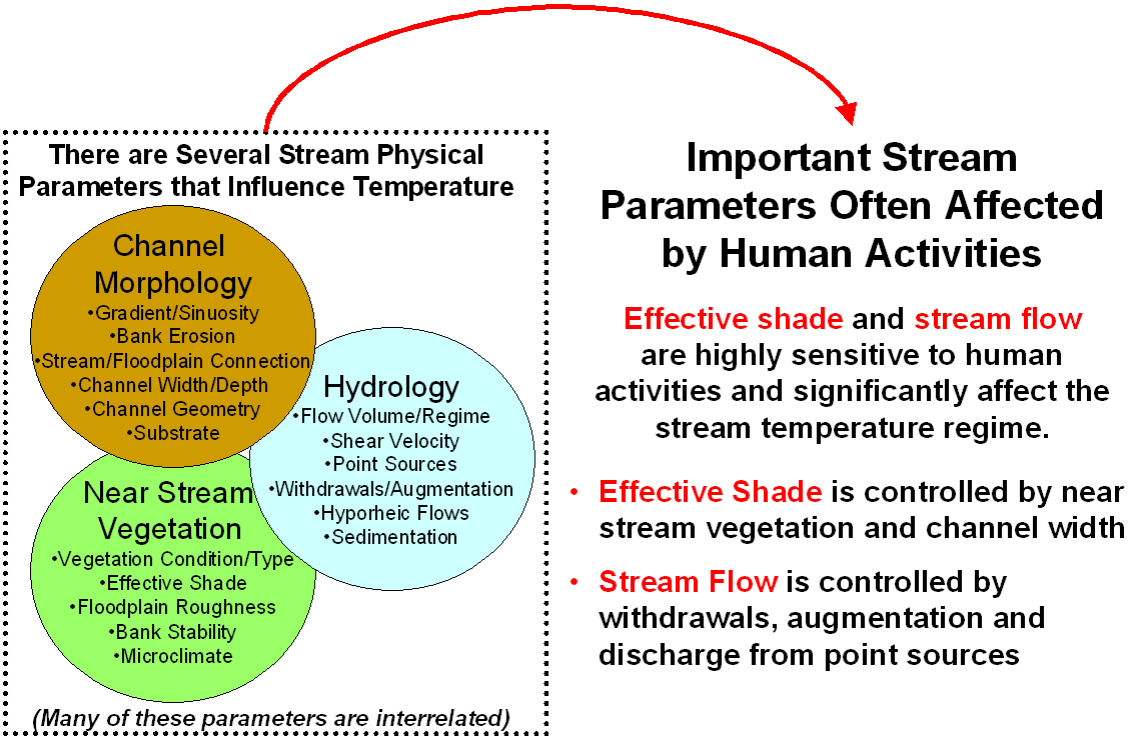
Tributaries and groundwater mixing change the heat of a stream segment when the stream temperature is different from the receiving water. Mixing simply changes the heat as a function of stream and inflow volumes and temperatures. Remote sensing using forward looking infrared radiometry can easily identify areas where heat change occurs due to mixing with surface and subsurface waters.

Example of Resulting Stream Temperatures After Stream Mixing With Variable Tributary Flows and Temperatures
Stream Flow = 5 cfs
Stream Temperature = 60°F



1.3.3 Human Sources of Stream Warming

The overriding intent of the Oregon stream temperature standard is to minimize human related stream warming. Brown (1969) identified temperature change as a function of heat and stream volume. Using this simple relationship, it becomes apparent that stream temperature change is a function of the heat transfer processes and mass transfer processes. To isolate the human influence on this expression, it is important to associate the human influence on the heat transfer processes and/or mass transfer processes.



Solar Radiation and Effective Shade

The solar radiation heat process considered in the stream thermal budget is often the most significant heat transfer process and can be highly influenced by human related activity. Decreased levels of stream shade increase solar radiation loading to a stream. The primary factors that determine of stream surface shade are near stream vegetation physical characteristics and channel width. Near stream vegetation height controls the shadow length cast across the stream surface and the timing of the shadow. Channel width determines the shadow length necessary to shade the stream surface. Near stream vegetation and channel width are sometimes interrelated in that stream bank erosion rates can be a function of near stream vegetation condition. **Human activities that change the type or condition of near stream land cover and/or alter stream channels by widening beyond appropriate channel equilibrium dimensions to levels that result in decreased stream surface shading will like have a warming effect on stream temperature.**

Stream surface shade is the primary control over the daytime rate of stream heating from direct beam solar radiation. Simply put, shade is a dominant control over the rate of stream heating.



Near Stream vegetation controls shadow length, and therefore, the timing of stream surface shade.



Near stream vegetation and **channel morphology** conditions are highly interrelated, since each affects the condition of the other.



Channel morphology determines the shadow length necessary to shade stream. In effect, channel morphology controls the size of the stream surface area.

Channel morphology condition and **near stream vegetation** combine to control the amount of stream surface shade shade that occurs on any given stream segment.



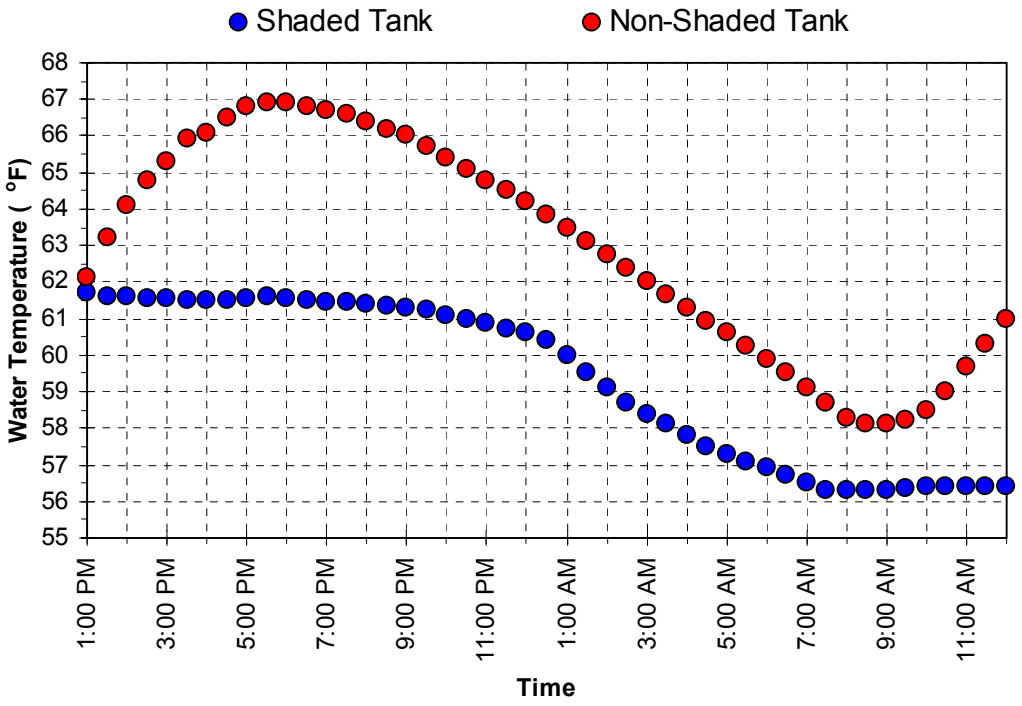
Two Recent Studies Relating Shade and Water Temperatures

The Effect of Shade on Water: A Tub Study
J. Moore, J. Miner and R. Bower
Department of Bioresource Engineering
Oregon State University - 1999

Two tanks with equal volumes of water and similar initial temperatures were insolated on the sides and bottom. One was exposed to August solar radiation, while the other was completely shaded. Results are presented in the graph below.

Tank Study - Seneca, Oregon

Two tanks with equal volume and as similar as possible with the exception that one is shaded and the other is not.



The Impact of Shade on the Temperature of Running Water
B. Petersen, T. Stringham and W. Krueger
Department of Rangeland Resources
Oregon State University - 1999

Results
"Shade from tarps provided a significant amount of protection from additional heating of the water at all shade levels tested… affirms the importance of even small amounts of shade in moderating stream heating."

Conclusion
"At the scale of this study, air temperature appears to have a minor impact on the temperature of water. The dominant factor seemed to be solar radiation."

Stream Flow Modifications

Recall the simple relationship presented by Brown (1969):

$$\Delta T_w \propto \frac{\Delta Heat}{Volume}.$$

It follows that large volume streams are less responsive to temperature change, and conversely, low flow streams will exhibit greater temperature sensitivity. Specifically, stream flow volume will affect the wetted channel dimensions (width and depth), flow velocity (and travel time) and the stream assimilative capacity. **Human related reductions in flow volume can have a significant influence of stream temperature dynamics, most likely increasing diurnal variability in stream temperature.**



Beyond the simple conception of reduced flow and corresponding reduced assimilative capacity, flow modifications can be highly complex in nature. Diversions can reroute surface waters through irrigation systems of various efficiencies. Often a portion of it irrigated water returns to the stream system at some lower gradient location. In the case of the Upper Klamath Lake drainage this is common. Diversions route water for long distances in canals and irrigation systems causing an immediate decrease in Instream flow volume. A secondary effect, captured in remotely sensed stream temperature data, is that the portion of irrigation flows returned to the stream system is often very warm, further increasing Instream temperatures.

1.3.4 Natural Sources and Stream Warming

Natural sources that may elevate stream temperature include drought, fires, insect damage to near stream land cover, diseased near stream land cover and windthrow and blowdown in riparian areas. The processes in which natural sources affect stream temperatures include increased stream surface exposure to solar radiation and decreased summertime flows. Legacy conditions (increased width to depth ratios and decreased levels of stream surface shading) that currently exist are, in part, due to natural disturbances. The extent of natural disturbances on near stream vegetation, channel morphology and hydrology in not well documented.

1.3.5 Cumulative Effects

"Cumulative effects are those effects on the environment that result from the incremental effect of the action when added to past, present and reasonably foreseeable future actions... Cumulative effects can result from individually minor but collectively significant actions taking place over a period of time". (Forest Ecosystem Management: An Ecological, Economic and Social Assessment. Report of the Forest Ecosystem Management Assessment Team)

Stream temperature changes result from upstream and local conditions. Incremental increases can combine to create relatively warm stream temperatures. Water has a relatively high heat capacity ($c_p = 10^3$ cal kg^{-1} K^{-1}) (Satterlund and Adams 1992). Conceptually, water is a heat sink. Heat energy that is gained by the stream is retained and only slowly released back to the surrounding environment. Any given measurement of stream temperature is the result of a multitude of processes occurring upstream, as well as those processes acting at the site of measurement. For this reason it is important to consider stream temperature at a stream network scale.

1.4 Implementation of Oregon DEQ's Stream Temperature Standard

Beneficial Uses for the Upper Klamath Lake Drainage Waters of the State
(**OAR 340-41-962 Table 19**)

- ✓ Public Domestic Water Supply[1]
- ✓ Private Domestic Water Supply[1]
- ✓ Industrial Water Supply
- ✓ Irrigation
- ✓ Livestock Watering
- ✓ Salmonid Fish Rearing[2, 3]
- ✓ Salmonid Fish Spawning[2, 3]
- ✓ Resident Fish and Aquatic Life
- ✓ Wildlife and Hunting
- ✓ Fishing
- ✓ Boating
- ✓ Water Contact Recreation
- ✓ Aesthetic Quality

Klamath Basin Temperature Standard
OAR 340-41-0962(2)(b)(A)

No measurable surface water temperature increase resulting from anthropogenic activities is allowed:

(i) In a basin for which salmonid fish rearing is a designated beneficial use, and in which surface water temperatures exceed 64°F (17.8°C);

(ii) In waters and periods of the year determined by the Department to support native salmonid spawning, egg incubation and fry emergence from the egg and from the gravels in a basin which exceeds 55°F (12.8°C);

(iii) In waters determined by the Department to support or to be necessary to maintain the viability of native Oregon bull trout when surface waters exceed 50°F (10.0°C);

(iv) In waters determined by the Department to be ecologically significant cold-water refugia[4];

(v) In stream segments containing federally listed Threatened and Endangered species if the increase will impair the biological integrity of the Threatened and Endangered population.

(vi) In Oregon waters when the dissolved oxygen (DO) levels are within 0.5 mg/l or 10% saturation of the water column or intergravel DO criterion for a given stream reach or subbasin;

(vii) In natural lakes.

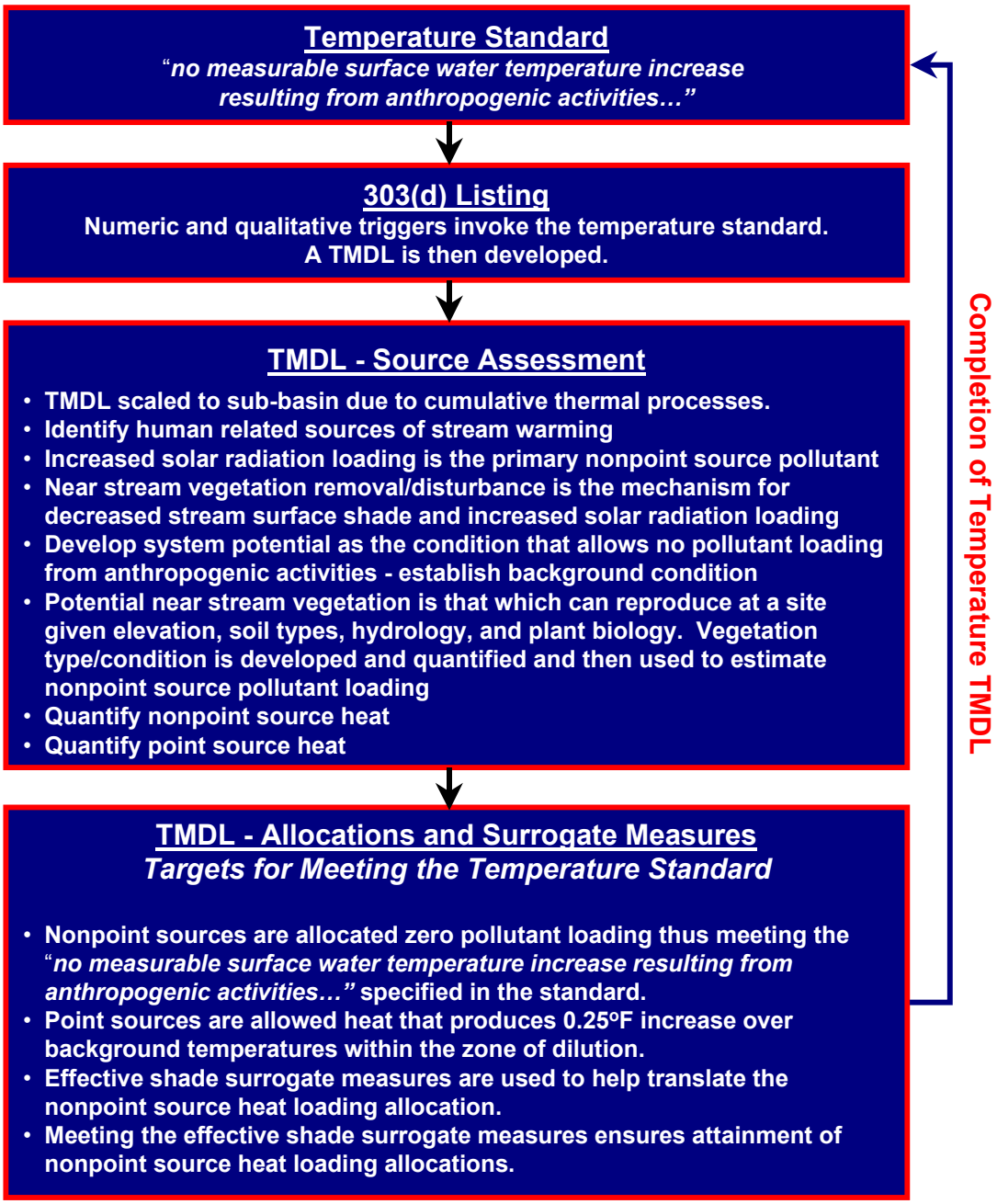
[1] While adequate pretreatment (filtration and disinfection) and natural quality to meet water quality standards.

[2] Where natural conditions are suitable for salmonid fish use.

[3] Salmonid fish rearing and spawning are the most sensitive beneficial use to be protected by the temperature water quality standard.

[4] Ecologically Significant Cold-Water Refugia exists when all or a portion of a water body supports stenotype cold-water species (flora or fauna) not otherwise supported in the sub-basin, and either: (a) maintains cold water temperatures (below numeric criterion) throughout the year relative to other stream segments throughout the sub-basin, or (b) supplies cold water to a receiving stream or downstream reach that supports cold water biota.

Summary of Temperature TMDL Development and Approach
Oregon DEQ Temperature Standard, 303(d) Listing and TMDL Development Process



1.4.1 Summary of Stream Temperature Standard

Human activities and aquatic species that are to be protected by water quality standards are deemed beneficial uses. Water quality standards are developed to protect the most sensitive beneficial use within a water body of the State. **The stream temperature standard is designed to protect cold water fish (salmonids) rearing and spawning as the most sensitive beneficial use.**

Several numeric and qualitative trigger conditions invoke the temperature standard. Numeric triggers are based on temperatures that protect various salmonid life stages. Qualitative triggers specify conditions that deserve special attention, such as the presence of threatened and endangered cold water species, dissolved oxygen violations and/or discharge into natural lake systems. The occurrence of one or more of the stream temperature trigger will invoke the temperature standard.

Once invoked, a water body is designated water quality limited. For such water quality limited water bodies, the temperature standard specifically states that "***no measurable surface water temperature increase resulting from anthropogenic activities is allowed"*** (OAR 340-41-0962(2)(b)(A)). Thermally impaired water bodies in the Upper Klamath Lake drainage are subject to the temperature standard that mandates a condition of no allowable anthropogenic related temperature increases.

1.4.2 Summary of Stream Temperature TMDL Approach

Stream temperature TMDLs are generally scaled to a subbasin or basin and include all perennial surface waters with salmonid presence or that contribute to areas with salmonid presence. Since stream temperature results from cumulative interactions between upstream and local sources, the TMDL considers all surface waters that affect the temperatures of 303(d) listed water bodies. For example, the Williamson River is water quality limited for temperature. To address this listing in the TMDL, the Williamson River and all major tributaries are included in the TMDL analysis and TMDL targets apply throughout the entire stream network. This broad approach is necessary to address the cumulative nature of stream temperature dynamics.

The temperature standard specifies that "***no measurable surface water temperature increase resulting from anthropogenic activities is allowed***". An important step in the TMDL is to examine the anthropogenic contributions to stream heating. The pollutant is heat. The TMDL establishes that that the anthropogenic contributions of nonpoint source solar radiation heat loading results from varying levels of decreased stream surface shade throughout the sub-basin. Decreased levels of stream shade are caused by near stream land cover disturbance/removal and channel morphology changes. Other anthropogenic sources of stream warming include stream flow reductions and warm surface water return flows.

System potential as defined in the TMDL as the combination of potential near stream land cover condition and potential channel morphology conditions. Potential near stream land cover is that which can grow and reproduce on a site, given: climate, elevation, soil properties, plant biology and hydrologic processes. Potential channel morphology is developed using an estimate of width to depth ratios appropriate for the Rosgen channel type regressed from regional curves. System potential does not consider management or land use as limiting factors. **In essence, system potential is the design condition used for TMDL analysis that meets the temperature standard by minimizing human related warming.**

- System potential <u>is</u> an estimate of the condition where anthropogenic activities that cause stream warming are minimized.
- System potential <u>is not</u> an estimate of pre-settlement conditions. Although it is helpful to consider historic land cover patterns, channel conditions and hydrology, many areas have been altered to the point that the historic condition is no longer attainable given drastic changes in stream location and hydrology (channel armoring, wetland draining, urbanization, etc.).

All stream temperature TMDLs allocate heat loading. Nonpoint sources are expected to eliminate the anthropogenic portion of solar radiation heat loading. Point sources are allowed heating that results in less than 0.25^{o}F increase in a defined mixing zone. Allocated conditions are expressed as heat per unit time (kcal per day). The nonpoint source heat allocation is translated to effective shade surrogate measures that linearly translates the nonpoint source solar

radiation allocation. Effective shade surrogate measures provide site-specific targets for land managers. And, attainment of the surrogate measures ensures compliance with the nonpoint source allocations.

1.4.3 Limitations of Stream Temperature TMDL Approach

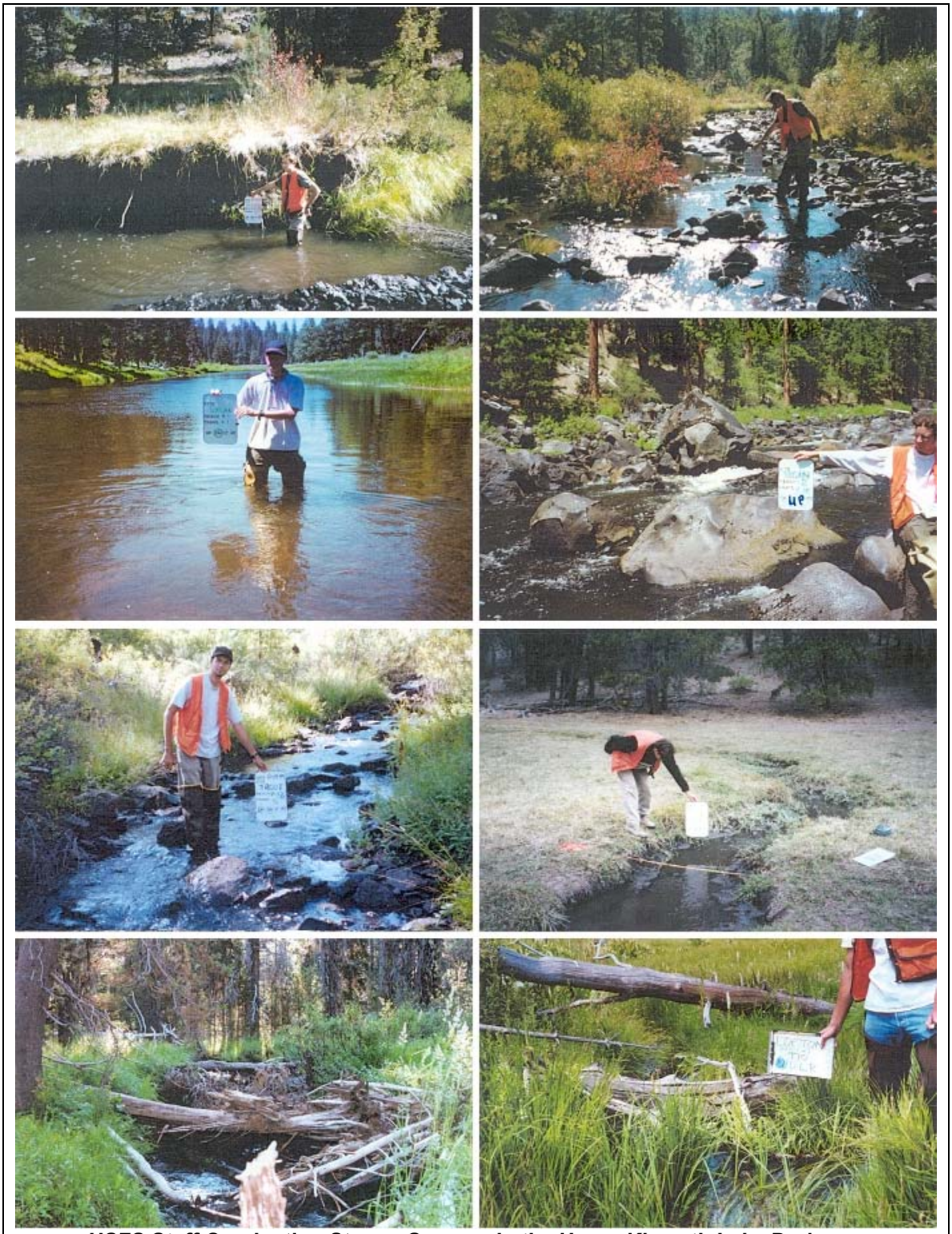
It is important to acknowledge limitations to analytical outputs to indicate where future scientific advancements are needed and to provide some context for how results should be used in regulatory processes, outreach and education and academic studies. The past decade has brought remarkable progress in stream temperature monitoring and analysis. Undoubtedly there will be continued advancements in the science related to stream temperature.

While the stream temperature data and analytical methods presented in TMDLs are comprehensive, there are limitations to the applicability of the results. Like any scientific investigation, research completed in a TMDL is limited to the current scientific understanding of the water quality parameter and data availability for other parameters that affect the water quality parameter. Physical, thermodynamic and biological relationships are well understood at finite spatial and temporal scales. However, at a large scale, such as a subbasin or basin, there are limits to the current analytical capabilities.

The state of scientific understanding of stream temperature is evolving, however, there are still areas of analytical uncertainty that introduce errors into the analysis. Three major limitations should be recognized:

- Current analysis is focused on a defined critical condition. This usually occurs in late July or early August when stream flows are low, radiant heating rates are high and ambient conditions are warm. However, there are several other important time periods where data and analysis is less explicit. For example, spawning periods have not received such a robust consideration.
- Current analytical methods fail to capture some upland, atmospheric and hydrologic processes. At a landscape scale can these exclusions can lead to errors in analytical outputs. For example, methods do not currently exist to simulate riparian microclimates at a landscape scale.
- In some cases, there is not scientific consensus related to riparian, channel morphology and hydrologic potential conditions. This is especially true when confronted with highly disturbed sites, meadows and marshes, potential hyporheic/subsurface flows, and sites that have been altered to a state where potential conditions produce an environment that is not beneficial to stream thermal conditions (such as a dike).

CHAPTER 2. AVAILABLE DATA



USFS Staff Conducting Stream Surveys in the Upper Klamath Lake Drainage

Terms Used in this Chapter

Canopy Cover/Density – The percentage of the area vegetation canopy/cover relative to a specific area. Commonly measured on the ground with a densiometer or with aerial photos in plan view.

Channel Morphology – The structure, form and evolution of stream channels.

Continuous Data - Data that is collected at consistent intervals over a specified time period.

Emissivity –The ratio of the actual emitted radiance to that of an ideal blackbody. Emissivity ranges from 0 to 1 (where 1 would be a blackbody) and is a term in the Steffan-Boltzmann Law for black body thermal radiation.

Effective Shade – The percentage of direct beam solar radiation attenuated and scattered before reaching the ground or stream surface. Commonly measured with a Solar Pathfinder.

Forward Looking Infrared Radiometry (FLIR) – The collection of radiation data used in this analysis to quantify the temperature of streams and the surrounding environment.

Gage Data – Flow volume information collected at a fixed location over long time periods.

Geographic Information Systems (GIS) – A computer system designed to view, sample and create spatial data sets.

Ground Level Data - Data collected where staff visited a site.

Hydrology - The scientific study of the water of the earth, its occurrence, circulation and distribution, its chemical and physical properties, and its interaction with its environment, including its relationship to living things.

Longitudinal Direction – Parallel to the stream flow direction.

NPDES – National Pollutant Discharge Elimination System established by the CWA

Near Stream Land Cover – Vegetation or other physical structures occur in the near stream area.

Nonpoint Sources – Pollutants that originates from dispersed locations such as, but not limited to, agricultural land uses, forestry and background sources.

Point Sources – Pollution that originates from a fixed location such as industrial waste.

Remotely Sensed Data - Data collected from an aerial or satellite based platform.

Rosgen Stream Type – Stream groupings that are based on basic channel and valley measurements.

Transverse Direction - Perpendicular to the stream flow direction

2.1 Ground Level Data

Several ground level data collection efforts have been completed for the Upper Klamath Lake drainage. Available ground level data sources are included and are discussed in detail in this chapter. Specifically, this stream temperature analysis relied on the following data types: continuous temperature data (USFS, DEQ, LWWG[5]), flow volume - gage data and instream measurements (USGS, USFS), near stream land cover surveys (USFS), channel morphology surveys (USFS) and effective shade measurements (USFS).

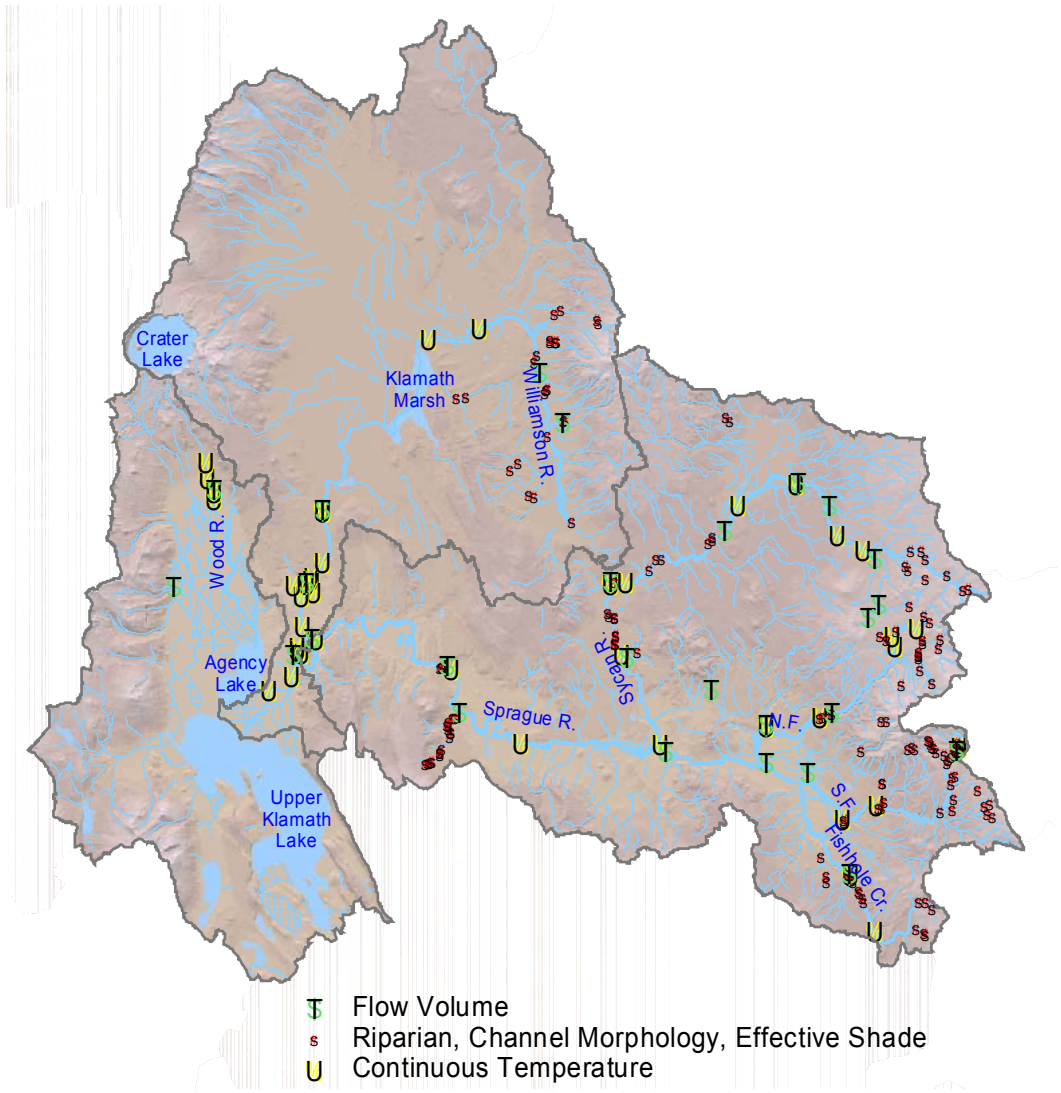


Figure 2-1. *Ground level data collection sites. Extensive ground level data has been collected for stream temperature, stream flow, riparian vegetation, channel morphology and effective shade.*

[5] LWWG - Lower Williamson Watershed Group

2.1.1 Continuous Temperature Data

Continuous temperature data are used in this analysis to:

- *Calibrate stream emissivity for forward looking infrared radiometry,*
- *Calculate temperature statistics and assess the temporal component of stream temperature,*
- *Calibrate temporal temperature simulations.*

Continuous temperature data is collected at one location for a specified period of time, usually spanning several summertime months. Measurements were collected using thermistors[6] and data from these devices are routinely checked for accuracy. Continuous temperature data were collected in 1999 at forty-two sites. ODEQ processed all of these data sets for the seven-day moving average maximum stream temperature (i.e., seven-day statistic). **Figure 2-2** displays continuous temperature data monitoring locations and seven-day moving average maximum daily temperatures. **Figures 2-3** to **2-8** graph temporal data (i.e. seasonal and daily) for selected locations in the Williamson, Sprague and Wood River drainages. **Table 2-1** lists the seven-day moving average daily maximum stream temperatures and the monitoring location description.

Seasonal variations in stream temperature are pronounced. The warmest stream temperatures occurred in late July, 1999. Data from previous years indicates that the seasonally warmest stream temperatures can occur anytime in June, July and August. Between May and October stream temperatures at many sites exceeded temperature numeric criterion[7]. Lower mainstem reaches of the Williamson, Sprague and Sycan Rivers all experience stream temperatures in the mid-70^{o}F range. Tributary temperatures were highly variable.

Calculated seven-day moving average maximum stream temperatures indicate a large extent of the Williamson, Sprague and Sycan River systems exceed the 64^{o}F numeric trigger in Oregon's stream temperature standard. The majority of stream segments experience summertime daily stream temperatures in the low to mid-70^{o}F range for long periods of time between May and October.

Areas where seasonal stream temperatures remain below the 64^{o}F numeric trigger are limited to upper headwater reaches and at localized stream segments with mass transfers of cold water from subsurface sources. Spring Creek, Larkin Springs, Wickiup Spring, Williamson River Spring and Kamkaun Spring are good examples of large groundwater sources that have a significant cooling effect on receiving surface waters. The Wood River system has daily maximum stream temperatures in the low to mid 50^{o}F range.

This stream temperature analysis is focused on the Williamson and Sprague River systems, where stream temperatures exceed the numeric triggers listed in Oregon's stream temperature standard.

6 Thermistors are small electronic devices that are used to record stream temperature at one location for a specified period of time.

7 Numeric criteria in the standard apply to salmonid rearing (64^{o}F), spawning (55^{o}F) and bull trout presence (50 ^{o}F).

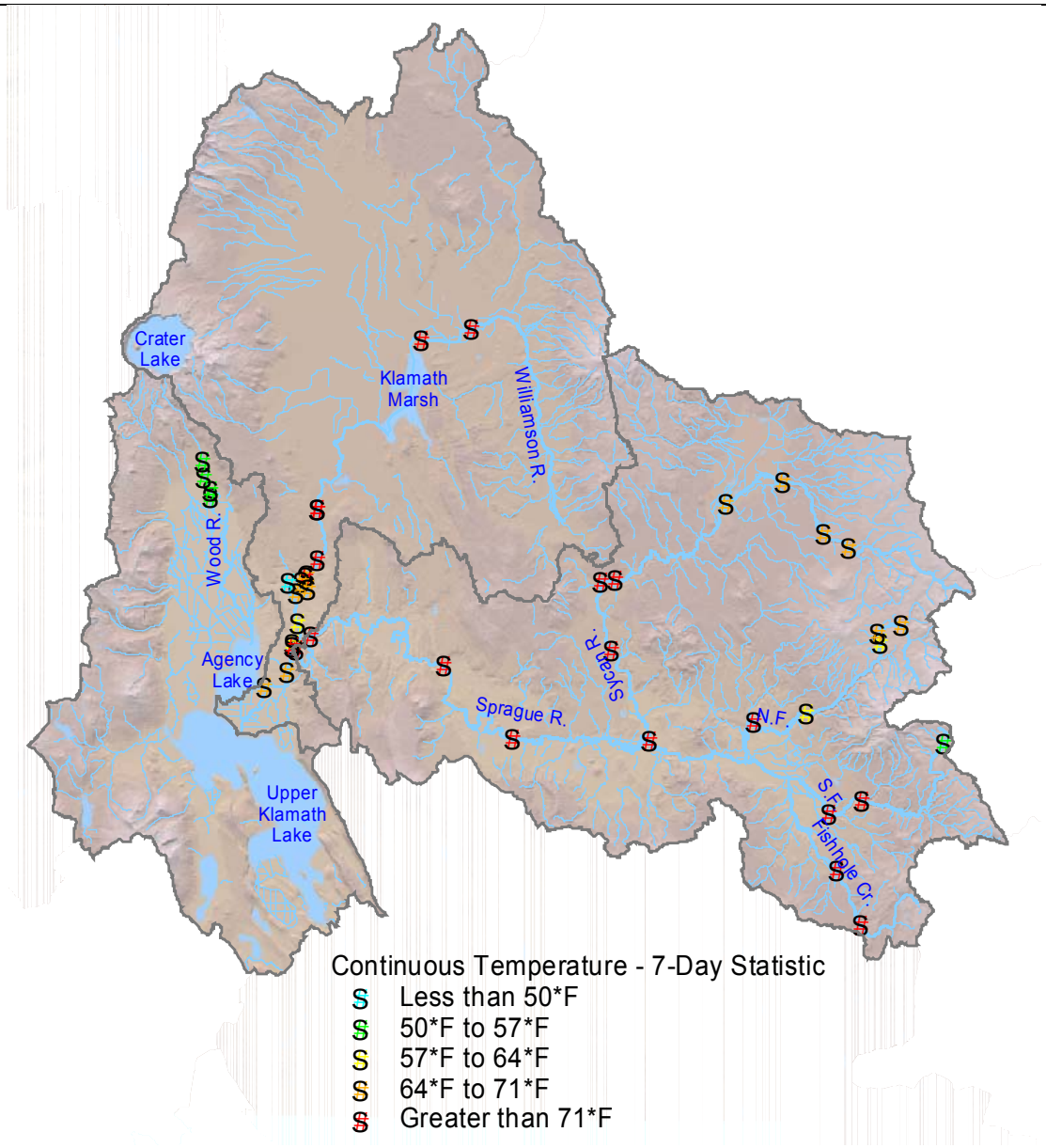


***Figure 2-2**. Continuous stream temperature measurement locations - Forty-two instream continuous temperature measurements were collected in 1999. Maximum seven-day moving average daily maximums (7-day statistic) suggest that temperatures are highly variable throughout the Upper Klamath Lake Drainage.*

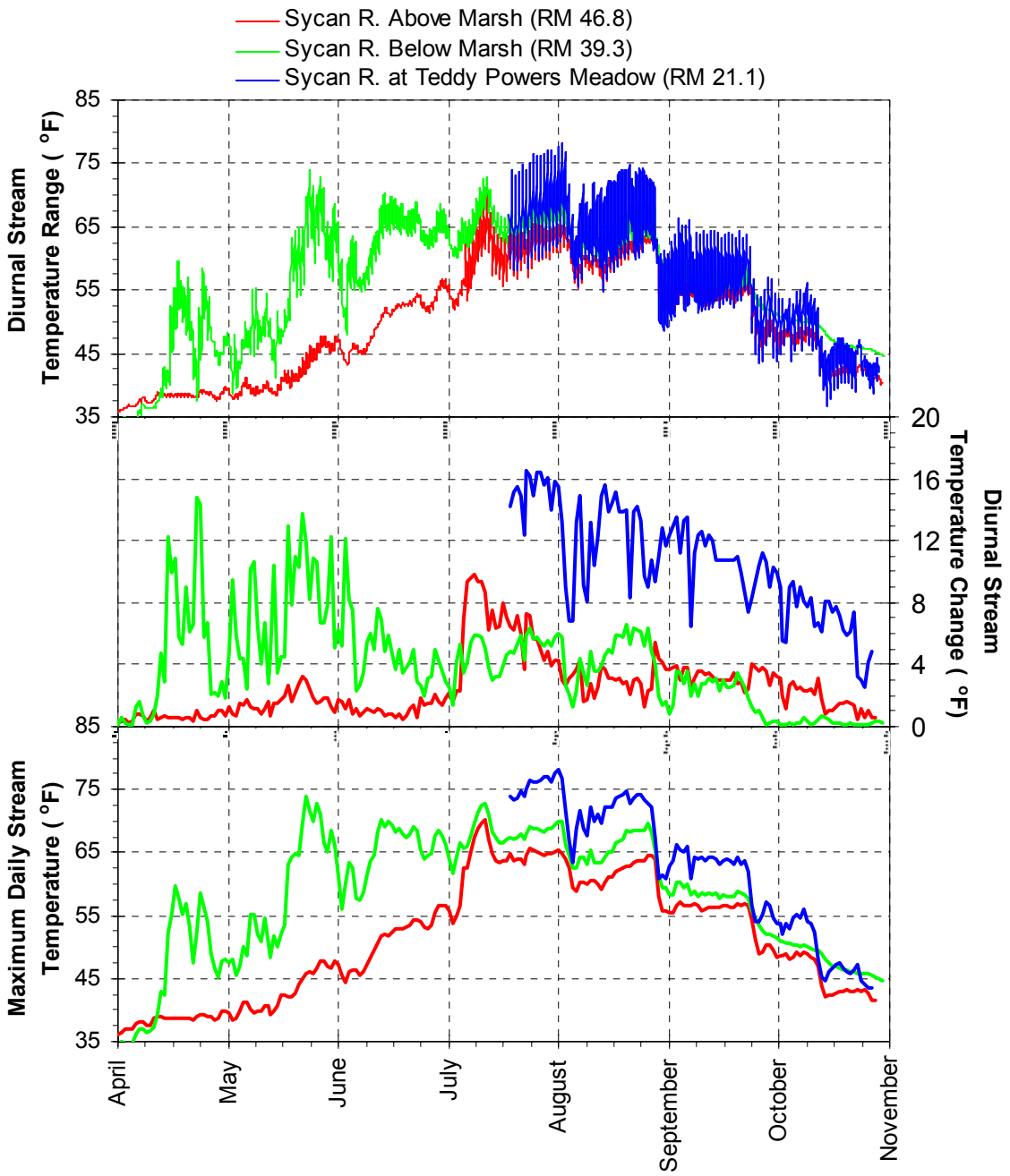


Figure 2-3. *Sycan River continuous temperature data (ODEQ and USFS data, 1999).*

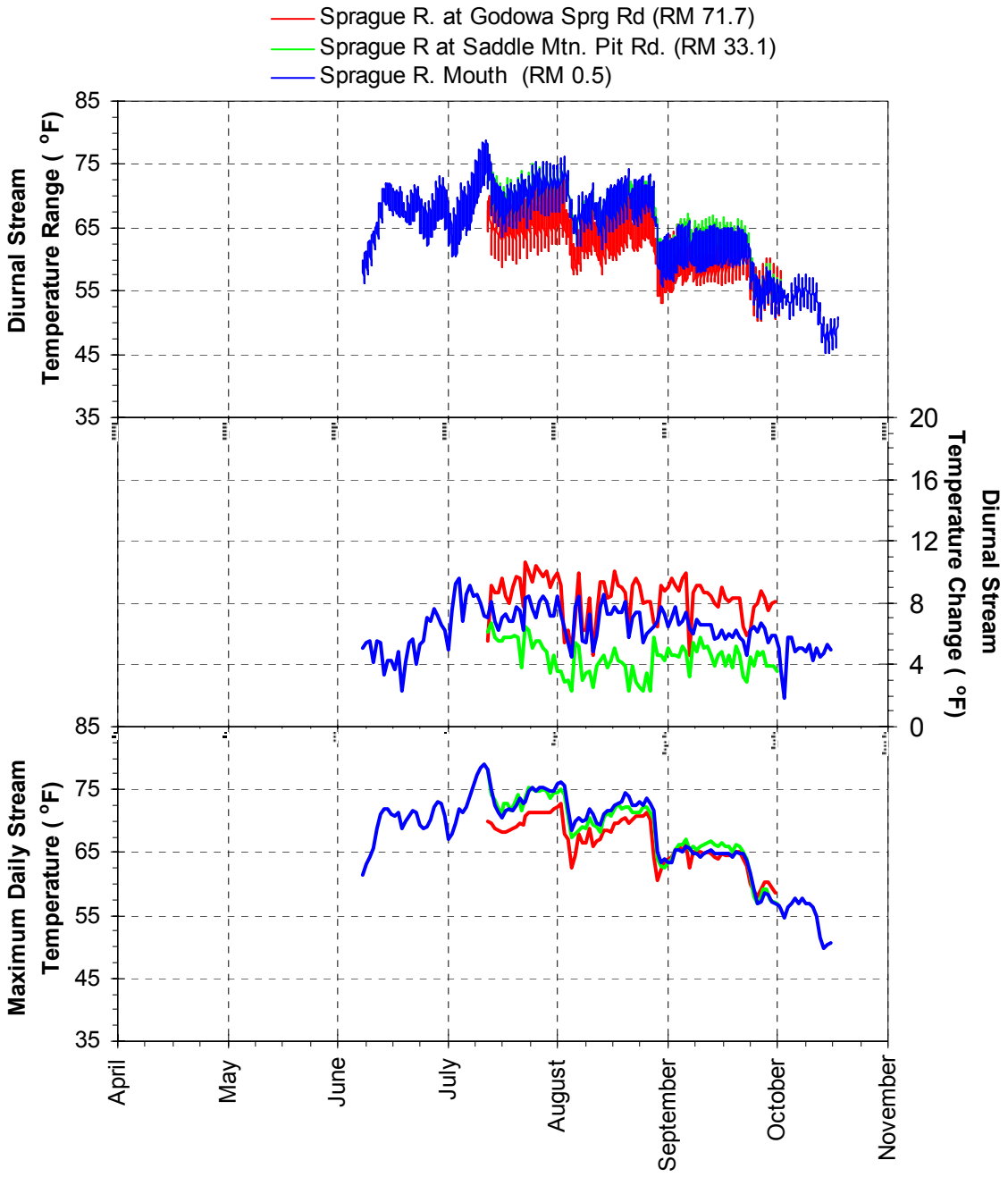


***Figure 2-4**. Sprague River continuous temperature data (ODEQ and USFS data, 1999).*

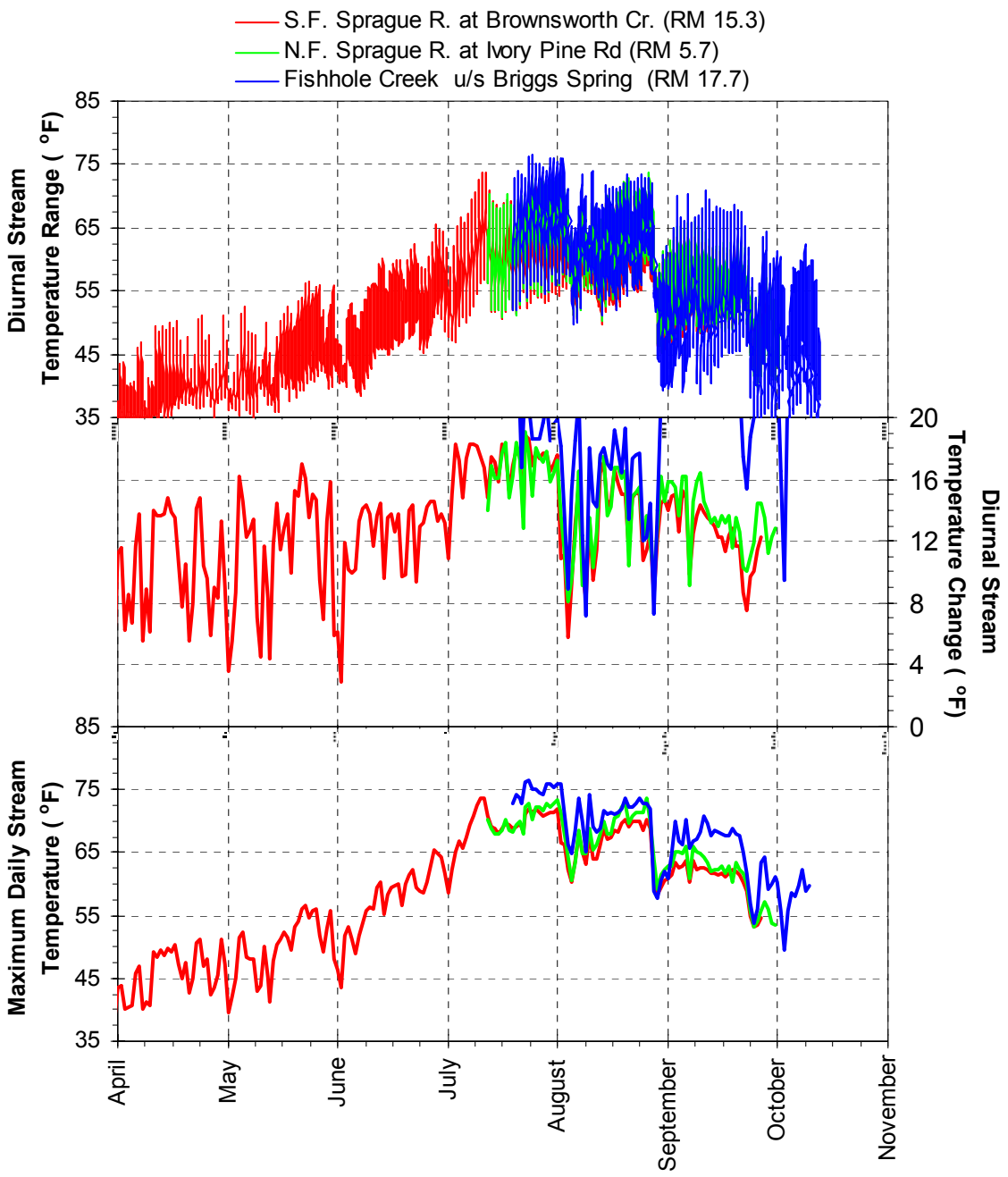


Figure 2-5. *Sprague River Tributary continuous temperature data (ODEQ and USFS data, 1999).*

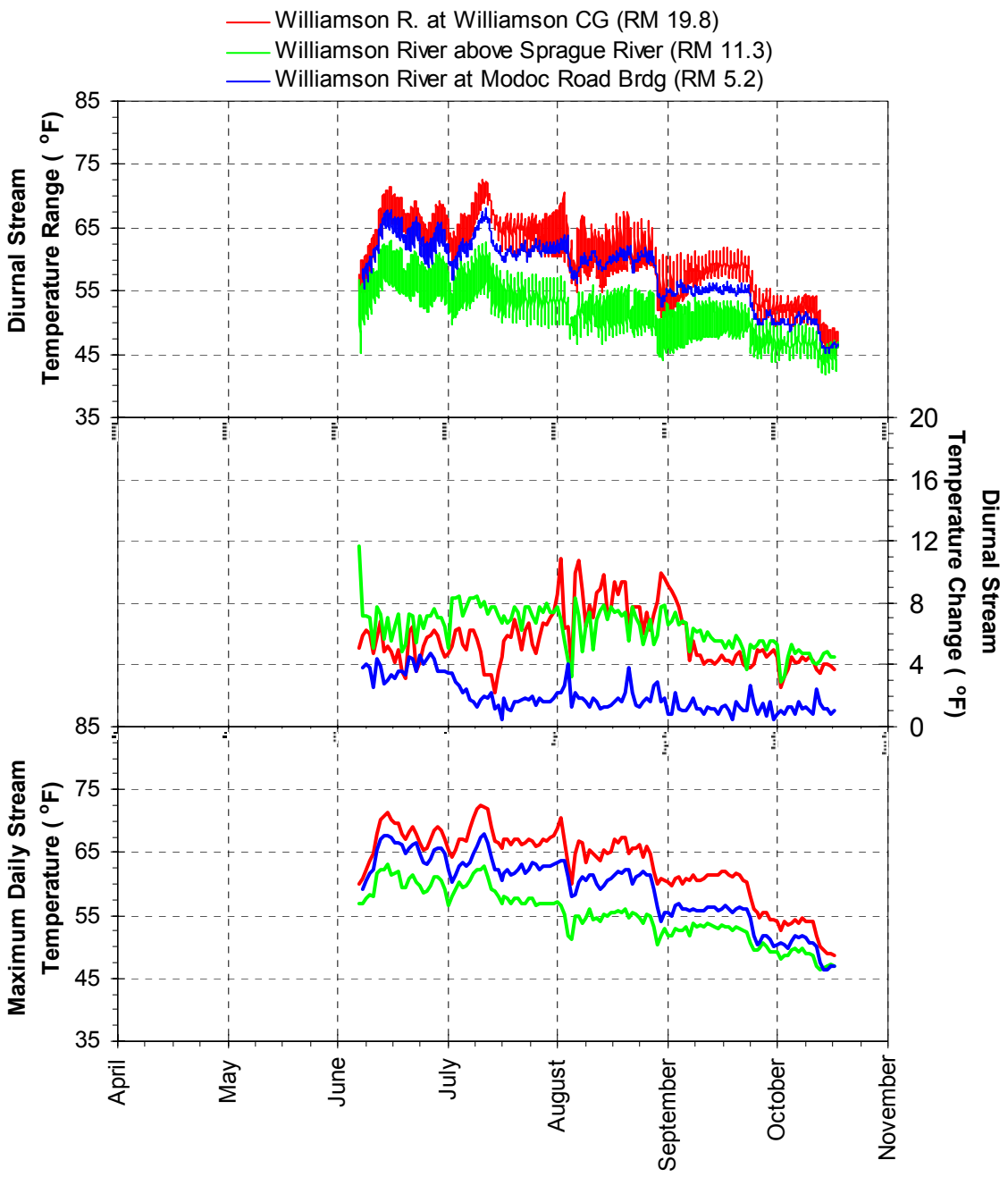


***Figure 2-6**. Williamson River continuous temperature data (ODEQ and LWWG data, 1999).*

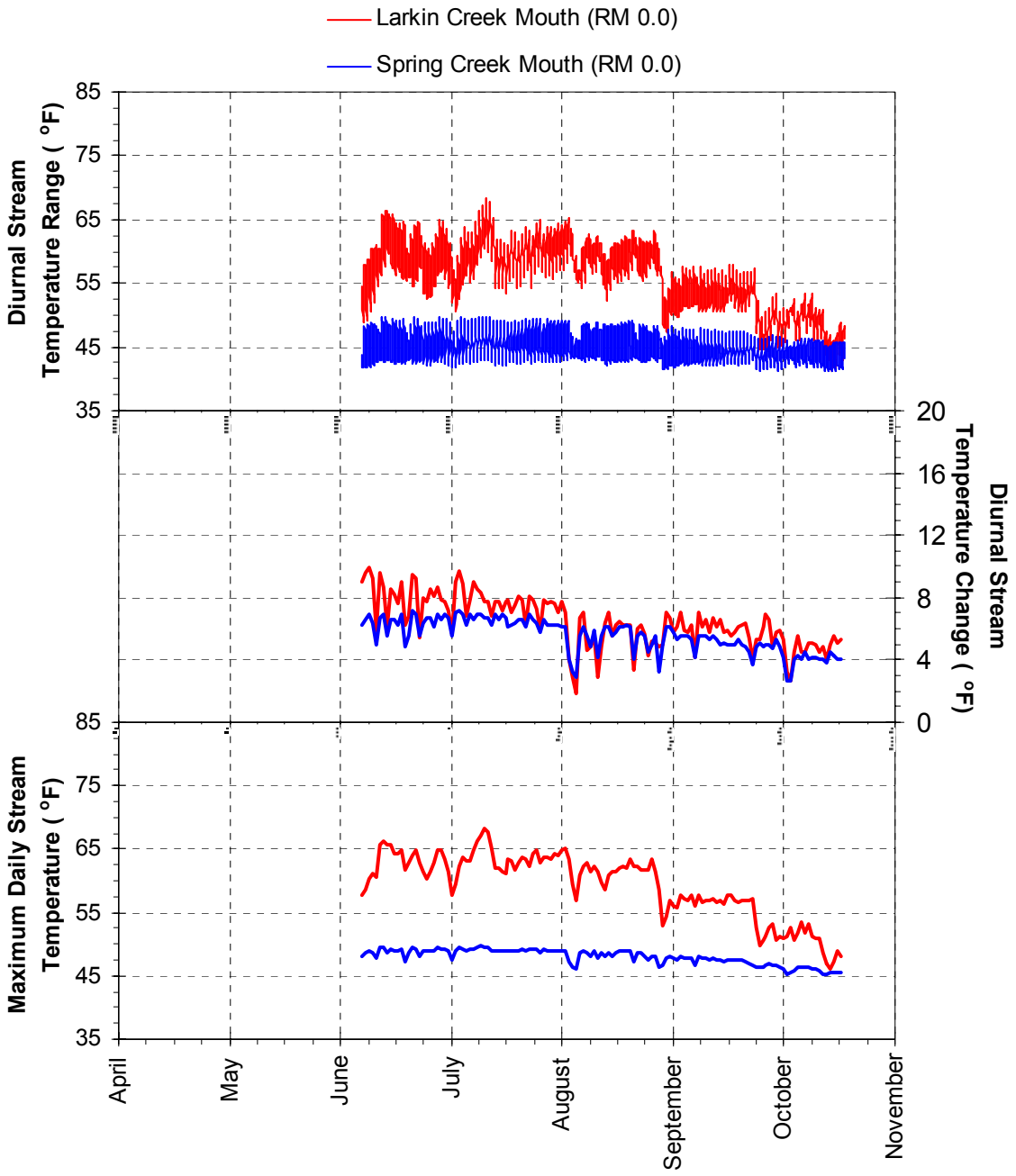


Figure 2-7. *Williamson River tributary continuous temperature data (ODEQ and LWWG data, 1999).*

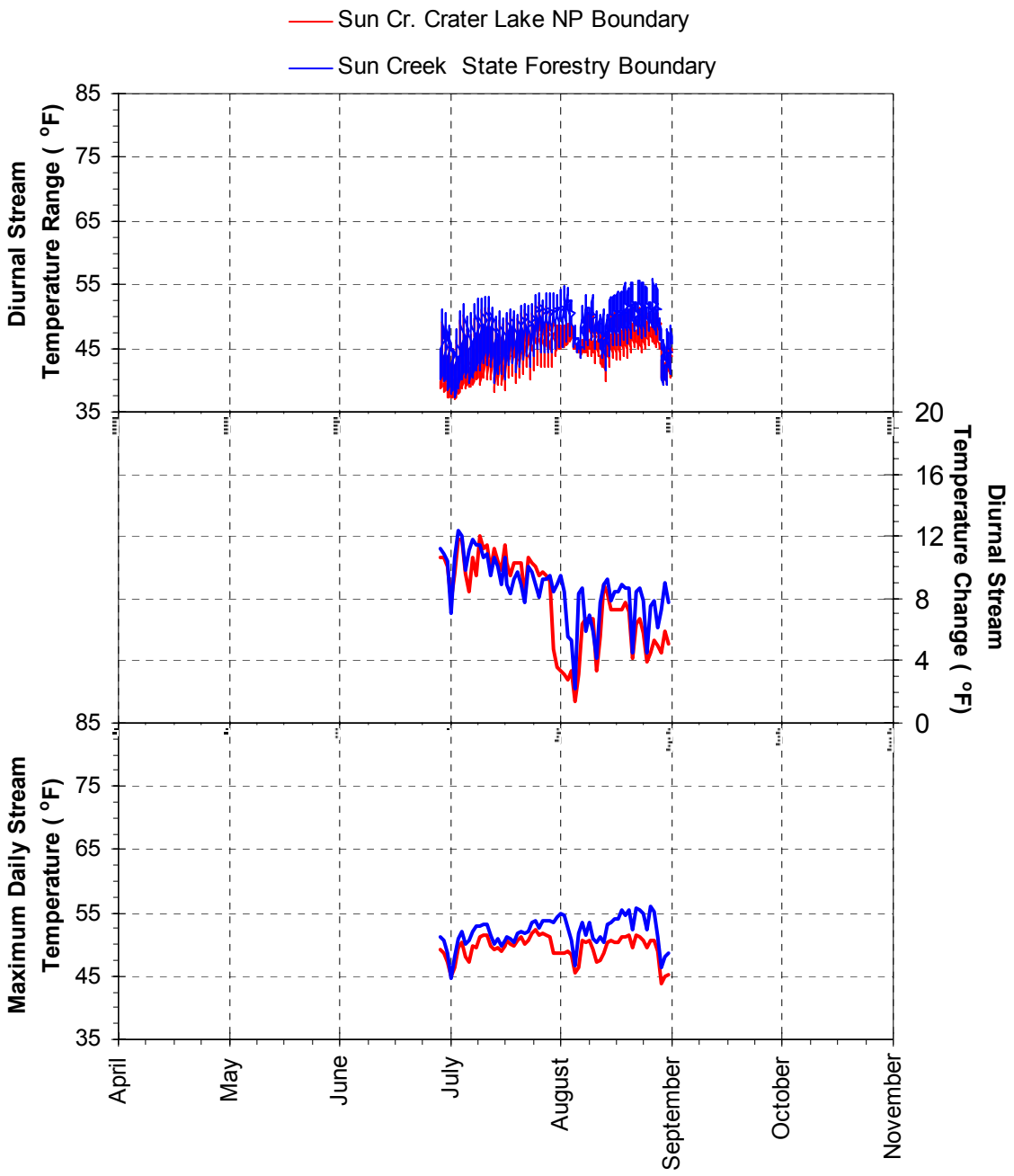


Figure 2-8. *Sun Creek (Wood River tributary) continuous temperature data (ODEQ and USFS data, 1999).*

Table 2-1. Continuous Temperature Data - 7-Day Statistics

	Site Name	River Mile (OWRD)	Distance from Headwaters (miles)	Date	7-Day Statistic (°F)
Sycan	Sycan River at Pike's Crossing	57.5	14.0	07/28/99	67.1
	Sycan River at Emigrant Crossing	54.4	17.1	07/09/99	67.3
	Sycan River above Marsh	46.8	24.8	07/09/99	67.6
	Sycan River below Marsh	39.3	32.2	05/23/99	70.8
	Sycan River upstream Teddy Powers Meadow	21.1	50.4	07/29/99	72.8
	Sycan River downstream Teddy Powers Meadow	19.5	52.0	07/29/99	77.1
	Sycan River at Coyote Bucket	11.9	59.6	07/29/99	74.9
S.F.	South Fork Sprague River upstream Corral Creek	30.3	1.8	07/10/99	55.5
	South Fork Sprague River near Brownsworth Creek	15.3	16.7	07/09/99	71.4
	South Fork Sprague River at Picnic Area	11.0	21.0	07/28/99	72.5
N.F.	North Fork Sprague River at Lee Thomas Crossing	27.4	10.1	07/10/99	67.0
	North Fork Sprague River at Sandhill Crossing CG	24.1	13.4	07/28/99	70.1
	North Fork Sprague River at Sandhill Crossing	22.5	15.0	07/08/99	62.7
	North Fork Sprague River at Elbow	12.5	25.0	07/10/99	60.0
	North Fork Sprague River at Ivory Pine Road	5.7	31.8	07/28/99	72.5
Sprague	Fishhole Creek upstream Briggs Spring	17.7	9.1	07/29/99	75.4
	Fishhole Creek near Devil's Lake	11.1	15.7	08/22/99	76.7
	Sprague River above Williamson River	0.1	86.5	07/09/99	76.8
	Sprague River at Private Bridge in Chiloquin, OR	0.5	86.1	07/29/99	76.1
	Sprague River at Chiloquin Ridge Road	5.6	81.0	07/29/99	73.7
	Sprague River at Saddle Mountain Pit Road	33.1	53.6	07/26/99	74.7
	Sprague River at Sprague River Road Brdg - River Crest Rd	50.9	35.7	07/30/99	73.7
	Sprague River at Godowa Spring Road North of Beattly, OR	71.7	14.9	07/29/99	71.8
Williamson	Larkin Creek near Mouth			07/08/99	66.1
	Larkin Creek (Upper Site)			06/13/99	68.3
	Spring Creek			07/07/99	49.5
	Canyon Springs (data suspicious)	23.6	63.0	06/12/99	46.9
	Williamson River upstream Modoc Road Bridge	5.2	81.4	06/14/99	67.1
	Williamson River at Kirk Bridge	27.1	59.5	07/30/99	74.6
	Williamson River at Lonesome Duck Lodge	8.5	78.1	06/13/99	67.2
	Williamson River above Sprague River	11.3	75.3	06/13/99	62.0
	Williamson River at Williamson Camp Ground (LWWG)	19.8	66.8	07/09/99	71.1
	Williamson River at Williamson River Camp Ground (DEQ)	20.1	66.6	07/13/99	68.5
	Williamson River at Kirk Gage	27.1	59.5	08/20/99	74.8
	Williamson River at Military Crossing Road	51.2	35.5	07/29/99	76.2
	Williamson River at Silver Lake Road near Wildlife Refuge	56.2	30.4	07/29/99	74.8
	Williamson River below Sunnybrook Creek	17.2	69.4	07/10/99	69.3
	Williamson River above Rainbow Park Bridge	13.4	73.2	06/13/99	61.7
Sun	Sun Creek at Crater Lake NP Boundary			07/25/99	51.5
	Sun Creek at #3 Road			08/20/99	52.6
	Sun Creek above Bridge			08/20/99	53.7
	Sun Creek at State Forestry Boundary			08/20/99	54.8

2.1.2 Flow Volume - Gage Data and Instream Measurements

Flow volume data is used in this analysis to:

- *Develop mass balances,*
- *Derive regional curves (Bakke et al., 2000).*

Flow volume data was collected at thirty sites during the critical stream temperature period in August, 1999 by the U.S. Forest Service, U.S. Bureau of Reclamation and Oregon DEQ. These gage data and instream measurements (listed in **Table 2-2**) were used to develop flow mass balances for the Williamson and Sprague River systems. **Figure 2-9** displays measured August flow rates. Bakke et al. (2000) related bankfull channel dimensions to drainage area by developing regional curves based on flow and channel data collected in the Upper Klamath Lake drainage.

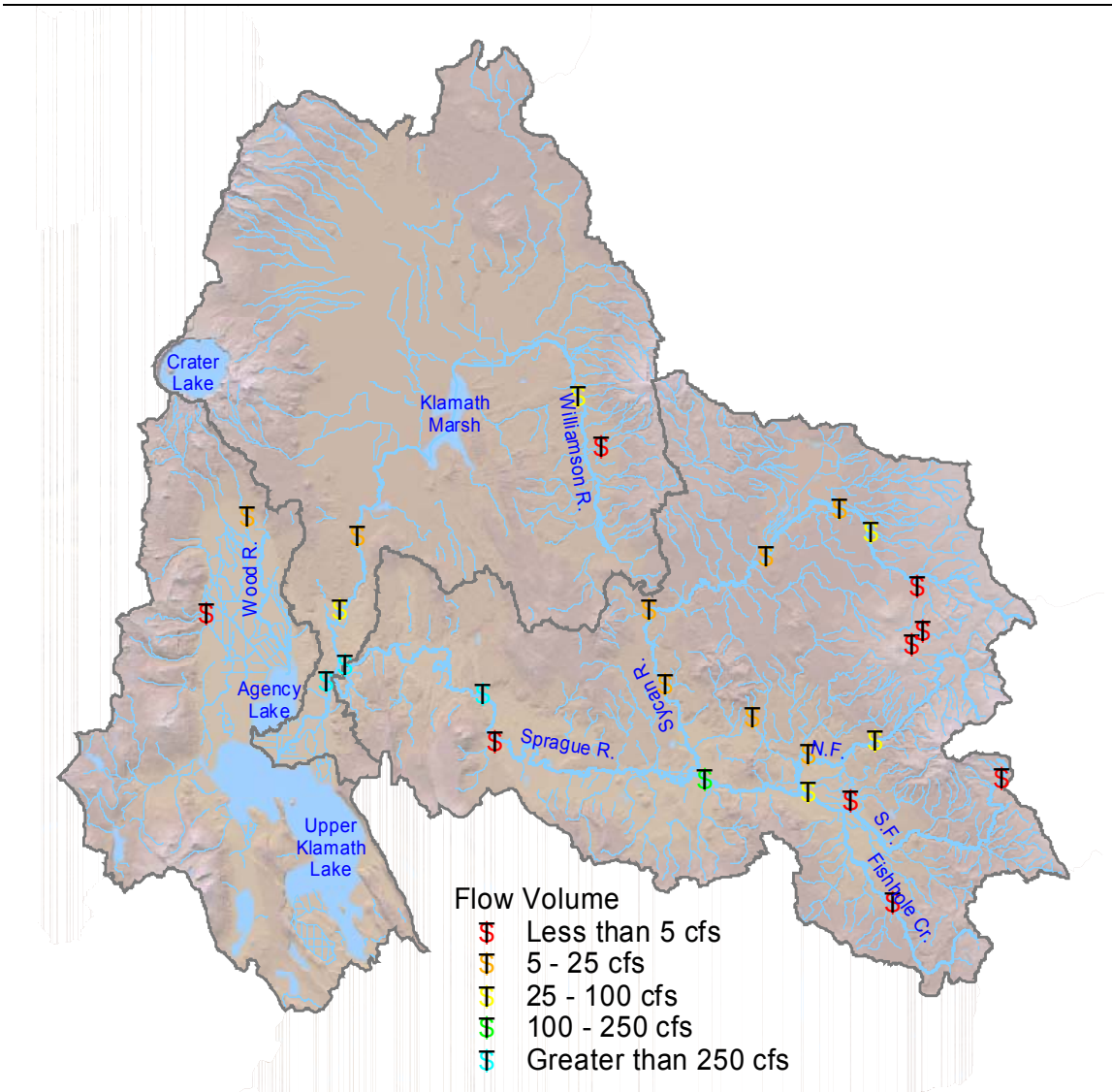


Figure 2-9*. Flow measurement locations (August, 1999). USFS, USBOR and ODEQ collected thirty measurements during this period from gages and instream measurements.*

Table 2-2. Flow Data (August Period)

	Location	Date[8]	Flow (cfs)	Agency - Method[9]
Sycan	Sycan River coyote bucket	8/18/99	17.2	USFS – I
	Sycan River Teddy Powers mdw	8/18/99	16.9	USFS – I
	Sycan River Above Marsh	8/23/99	7.3	USFS – G
	Sycan River Below Marsh	8/23/99	6.8	USFS – G
	Sycan River below Snake Creek near Beatty, OR	8/16/99	31.0	USGS – G
	Crazy Creek	8/20/99	1.2	USFS – I
	Watson Creek	8/11/99	0.8	USFS – I
	Paradise Creek headwaters	8/19/99	1.5	USFS – I
	Long Creek just upstream Sycan Marsh	8/16/99	47.8	USBIA – G
S.F	South Fork Sprague River u/s Corral Creek	8/10/99	4.2	USFS – G
	Deming Creek	8/24/99	3.1	USFS – G
N.F.	North Fork Sprague River Lee Thomas Meadow	8/19/99	13.6	USFS – G
	North Fork Sprague at Ivory Pine Rd, RM 5.5	8/11/99	14.7	ODEQ – I
	North Fork Sprague at Power Plant near Bly, OR	8/16/99	28.0	USGS – G
	Fivemile Creek	8/25/99	22.4	USFS – G
Sprague	Sprague River near Beatty, OR	8/12/99	180.0	USGS – G
	Sprague River at Lone Pine	8/12/99	449.1	USBIA – G
	Sprague River at Ivory Pine Road, RM 85.3	8/11/99	30.1	ODEQ – I
	Sprague River near Chiloquin, OR	8/12/99	353.0	USGS – G
	Fishhole Creek	8/24/99	1.3	USFS – G
	Trout Creek	8/18/99	2.5	USFS – I
Williamson	Williamson River @ Larkin Creek	8/10/99	43.5	USFS – I
	Williamson River below Sheep Creek near Lenz, OR	8/4/99	60.0	USGS – G
	Williamson River near Klamath Agency, OR	8/4/99	22.0	USGS – G
	Williamson River below Sprague near Chiloquin, OR	8/4/99	560.0	USGS – G
	Deep Creek	8/11/99	4.6	USFS – I
UKL	Sevenmile Creek	8/25/99	22.6	USFS – G
	Sun Creek	8/9/99	18.5	USFS – G
	Threemile Creek	9/3/99	3.3	USFS – I

[8] Date shown is either the day measured, or the day of FLIR if a gage.

[9] G = Instream gage, I = Instantaneous Instream Measurement

2.1.3 Stream Surveys

The USFS has been active in performing stream surveys in the Upper Klamath Lake drainage. Vast stream lengths have been surveyed in detail offering a wide array of ground level data. Stream survey data focuses on near stream land cover classification and measurements, extensive channel morphology measurements with Rosgen assessments and stream shade measurements.

The level of detail, quality of work and the large extent of stream surveys conducted by USFS staff is impressive. Their foresight and dedication to data collection has produced a large database of stream information that will serve as the basis to understanding and tracking complex interactions between stream channels, near stream land cover and human land use activities. This data set was heavily used by ODEQ in the analysis presented in this document.

2.1.3.1 Near Stream Land Cover

At each stream survey reach near stream land cover species and composition was identified, as well as, land cover height, canopy density and width estimations. The USFS followed the Kovalchick (1987) classification methodology that was an extension of plant associations developed by Hall (1973), Volland (1976) and Hopkins (1979a and b).

The primary focus of the Kovalchick classification system is to:

- *Describe the general geographic, topographic, edaphic, functional, and floristic features of riparian ecosystems.*
- *Describe successional trends and predict vegetation potential on disturbed riparian ecosystems.*
- *Present information on resource values and management opportunities.*
- *Contribute to the broad regional classification program of the USDA Forest Service Region 6.*

Text taken directly from Kovalchick, 1987

2.1.3.2 Channel Morphology and Rosgen Stream Classifications

Channel morphology data are used in this analysis to:

- *Validate GIS derived channel morphology data,*
- *Validate GIS derived Rosgen level I stream types.*

Extensive channel morphology measurements were taken at stream survey reaches. Data collection included multiple longitudinal measurements of several channel dimensions, incision, flood prone width estimates, stream gradient, stream aspect and transverse hill slope/topographic angles. Further, pebble counts were conducted to measure streambed sediments. These data allowed Rosgen stream type classifications that assess stream channel evolution and condition. Stream channels reach equilibrium with physical parameters and processes. Often human land use can alter these parameters and processes, and in turn, alter stream channel conditions. The USFS stream surveys were designed to assess stream channel morphology via Rosgen methodology.

Physical processes shape stream channels within a given drainage basin. These physical processes are the natural result of interrelated landscape and instream characteristics and interactions. Key parameters that affect stream channel evolution are: near stream land cover, stream flow regimes and erosion/deposition patterns.

Employing Rosgen stream characterizations helps make estimates of the evolution of stream conditions. Rosgen offers the premise that stream channels reach equilibrium with physical parameters and processes. Human land use can alter these parameters and processes, and in turn, alter stream channel conditions. Human land use can change the near stream vegetation

type and condition. Flow augmentation and withdrawal can change stream flow patterns. Erosion and depositional processes can increase from various landscape and instream human activities. By establishing the natural evolution patterns of a stream channel it may become possible to distinguish deviations caused by human land use activities.

Level I Rosgen stream classifications group streams (letters A through G) based on valley shape, channel patterns and channel slope and cross-section. GIS and remote sensing data can be used to estimate Level I Rosgen stream types at a landscape scale. Specifically, high-resolution GIS stream channel, gradient and sinuosity data can be derived at a stream network scale. By applying these GIS derived data in combination with selected ground level checkpoints, system-wide stream type estimates can be completed.

Identification of important valley morphology characteristics can also help identify stream morphology types. Rosgen states that "the interpretation of stream types as derived from an analysis of landforms and related valley types are reliable."[10] The analysis of valley type considers landform at a landscape scale. GIS analysis can be used to quantify valley slope, form/morphology, soil materials/texture and erosional process estimates. Level I stream types can be associated with specific valley types.

Rosgen Level II morphologic classifications considers all of the Level I parameters as well as substrate particle size, entrenchment ratio, width to depth ratio and sinuosity. Level II classifications can provide insight as to reach-specific sediment supply, sensitivity to disturbance and the potential for natural recovery. Generalized characteristics can be associated with each of the Level II Rosgen stream classes that relate channel morphology to sensitivity to disturbance, recovery potentials, sediment supply, streambank erosion potential and vegetation controlling influence. Rosgen (1994) presents these characteristics to provide guidance to riparian and sediment management.

In summary, level I stream types have been estimated for major streams using USFS ground level data and GIS data. These level I stream classifications are then used to group stream segments in the development of regional curves for channel width.

Geomorphic Characterization Parameters

Channel Patterns:	Single or Multiple Channels
Stream Slope:	Stream (Water Surface) Gradient
Valley Slope:	Longitudinal Valley Gradient
Sinuosity:	Stream Length Divided by Valley Length
Meander Width Ratio:	Belt Width Divided by Bankfull Width
Entrenchment Ratio:	Floodprone Width Divided by Bankfull Width
Width to Depth Ratio:	Bankfull Width Divided by Bankfull Depth

[10] D. Rosgen. 1996. Applied River Morphology. Wildland Hydrology. Pasoga Springs, Colorado. p. 4-11.

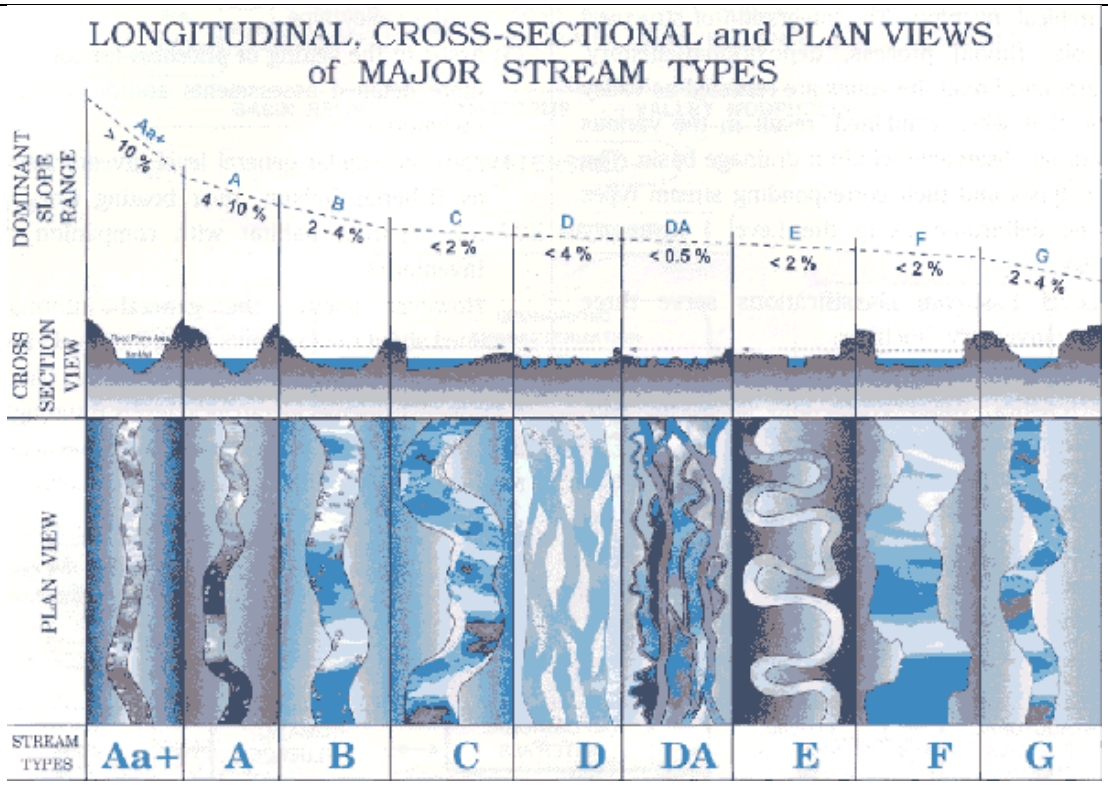


Figure 2-10. Slope Ranges, Cross-Sections and Plan Views of Level I Rosgen Stream Types *(Image from Rosgen, 1996)*

Table 2-3. Rosgen Stream Types
(Data from Rosgen, 1996)

Channel	Bed Slope	Sinuosity	Entrenchment Ratio	Meander Width Ratio	W:D	Description	Rosgen Channel Type
Single	High (5% - 10%)	**Low** (1.0 - 1.2)	**Low** (< 1.4)	**Low** Ave = 1.5 (1 - 3)	**Low** (< 12)	High Relief, Erosional/Depositional and Bedrock Features, Entrenched and Confined Streams w/ Cascading Reaches	Type A
	Moderate (2% - 4%)	**Moderate** (> 1.2)	**Moderate** (1.4 - 2.2)	**Low** Ave = 3.7 (2 - 8)	**Moderate** (> 12)	Moderate Relief, Moderate Entrenchment and W/D Ratio, Narrow Gently Sloping Valleys, Rapids Predominate w/ Scour Pools	Type B
	Low (< 2%)		**Low** (< 1.4)	**Low** Ave = 3.7 (2 - 8)	**Low** (< 12)	Gullies, Moderate Slopes, Low W/D Ratio, Narrow Valleys or Deeply Incised, Unstable, High Bank Erosion	Type G
		High (> 1.2)	**High** (> 2.2)	**High** Ave = 11.4 (4 - 20)	**Moderate/High** (> 12)	Broad Valleys w/ Terraces, Associated w/ Floodplains, Alluvial Soils Slightly Entrenched, Well Defined Meandering Channels	Type C
		Very High (> 1.5)	**High** (> 2.2)	**Very High** Ave = 24.2 (20 - 40)	**Very Low** (< 12)	Broad Valley/Meadows, Alluvial Materials w/ Floodplains, Highly Sensuous, Stable Well Vegetated Banks, Very Low W/D	Type E
		Moderate (> 1.2)	**Low** (< 1.4)	**Moderate** Ave = 5.3 (2 - 10)	**Moderate/High** (> 12)	Entrenched in Highly Weathered Material, Gentle Gradients, High W/D, Meandering Laterally, Unstable w/ High Bank Erosion Rates	Type F
Multiple	**Low** (< 4%)	n/a	n/a	**Low** Ave = 1.1 (1 - 2)	**Very High** (> 40)	Broad Valleys w/ Alluvium, Steeper Fans, Glacial Debris, Active Lateral Adjustment, Abundant Sediment Supply, Aggradational Processes, High Bedload and Bank Erosion	Type D
	Very Low (< 0.5%)	Variable	**High** (> 2.2)	n/a	**Low** (< 40)	Broad Low Gradient Valleys, Fine Alluvium, Multiple Channels, Laterally Stable w/ Broad Wetland Floodplains, Very Low Bedload, High Wash Load Sediment	Type DA

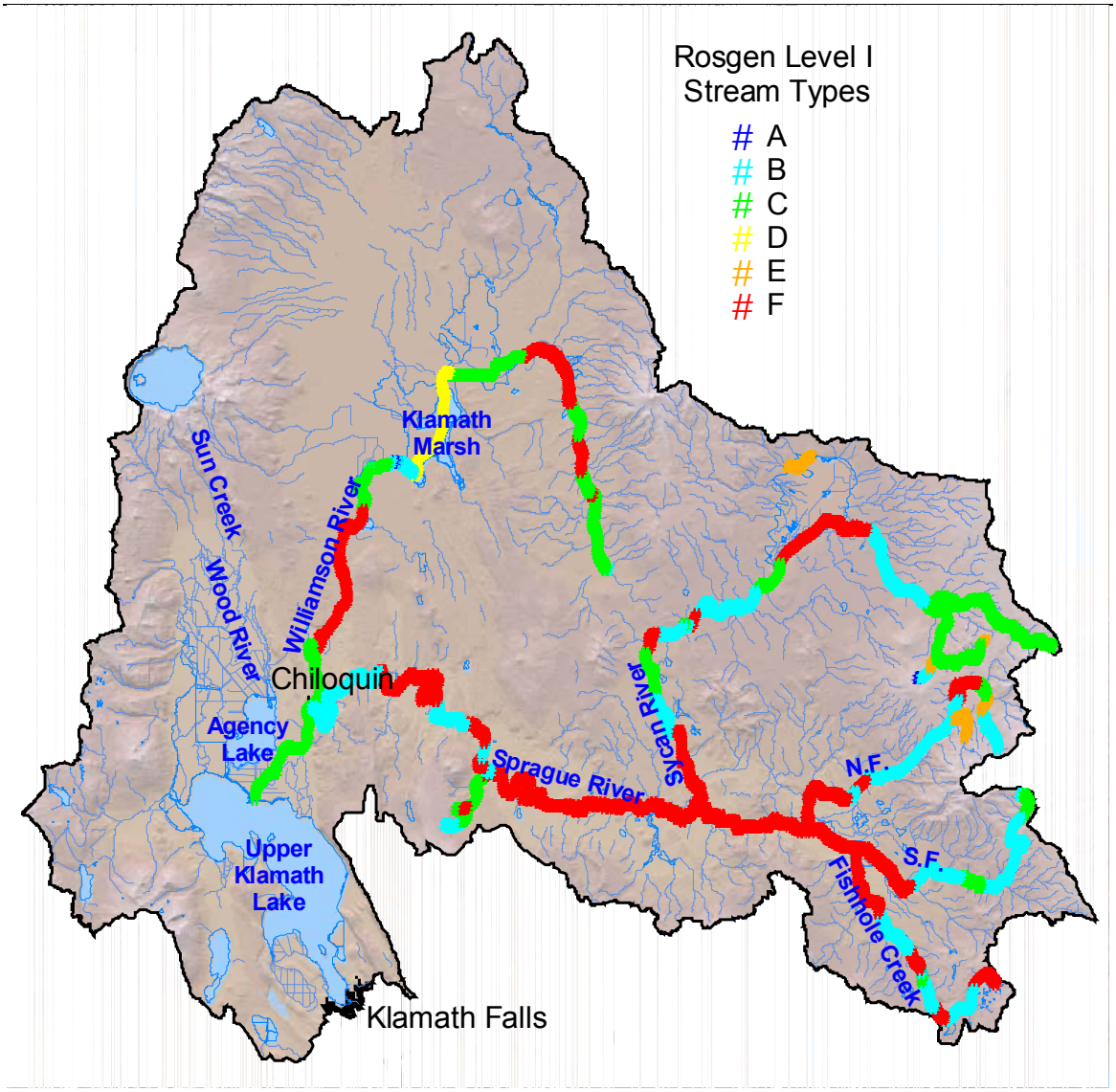


Figure 2-11. Level I Rosgen Stream Types *(USFS and DEQ Classifications)*

2.1.3.3 Effective Shade

Effective shade data are used in this analysis to:
- *Validate simulated effective shade data.*

Effective shade is an measurement of the portion of direct beam solar radiation that is attenuated and scattered before reaching the stream surface. A complete definition of effective shade is presented in **Section 4.2.1 Overview – Description of Shading Processes**. USFS staff measured effective shade with a solar pathfinder. Multiple measurements were collected longitudinally and then average along the survey reach. Effective shade can be highly variable when vegetation and channel morphology conditions are variable. Therefore, it is preferable to collect multiple measurements in along a reach and then average the values.



A Solar Pathfinder is used to measure effective shade. It can estimate solar radiation for any site throughout the year. An image of the surrounding shade producing features (i.e. vegetation and topography) is projected on to a disk that can then be read to give solar radiation levels.



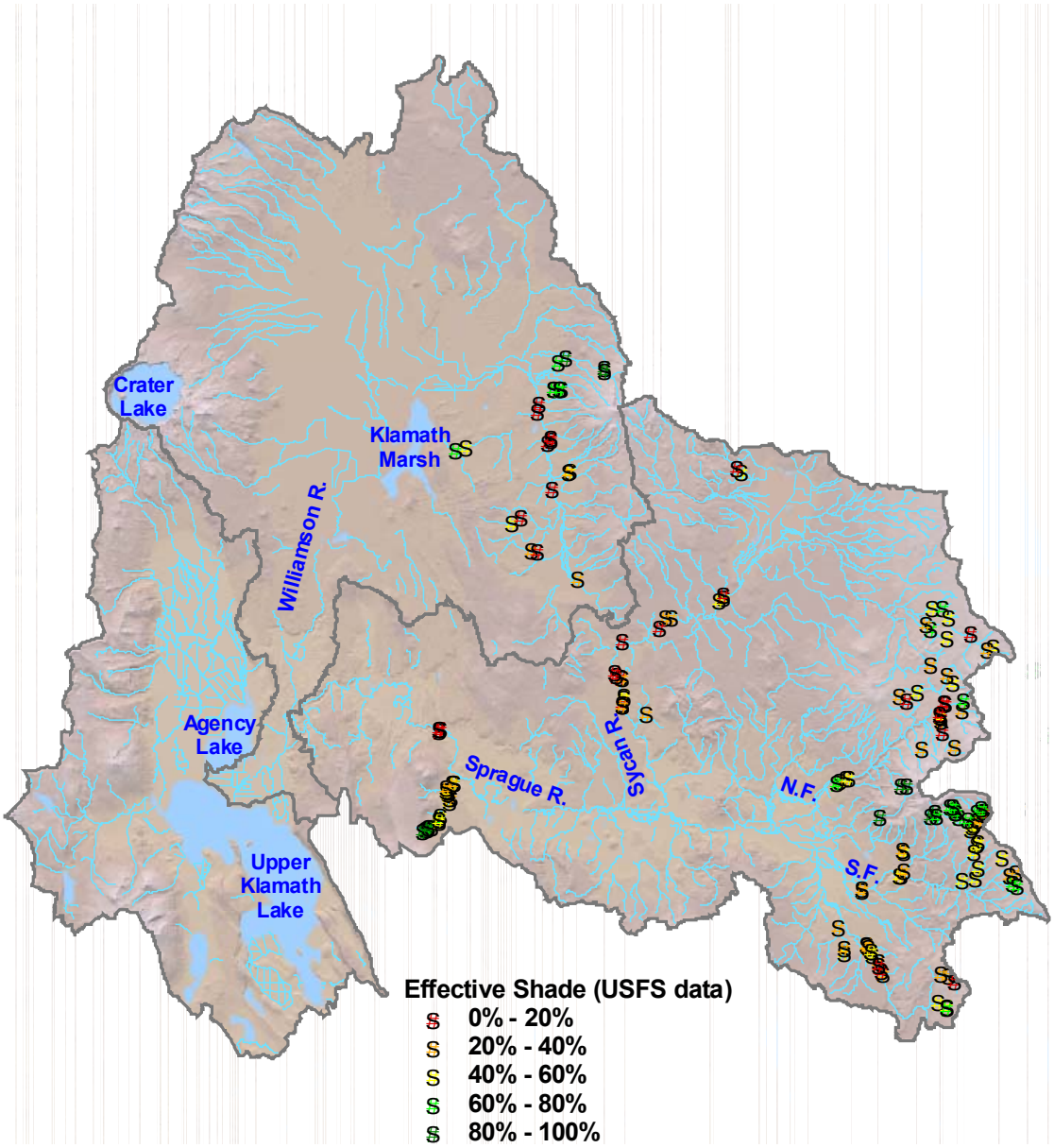


***Figure 2-12**. Ground level effective shade measurements. These values represent reach averages, where data were collected every 100 feet along a stream reach (USFS data).*

2.2 GIS and Remotely Sensed Data

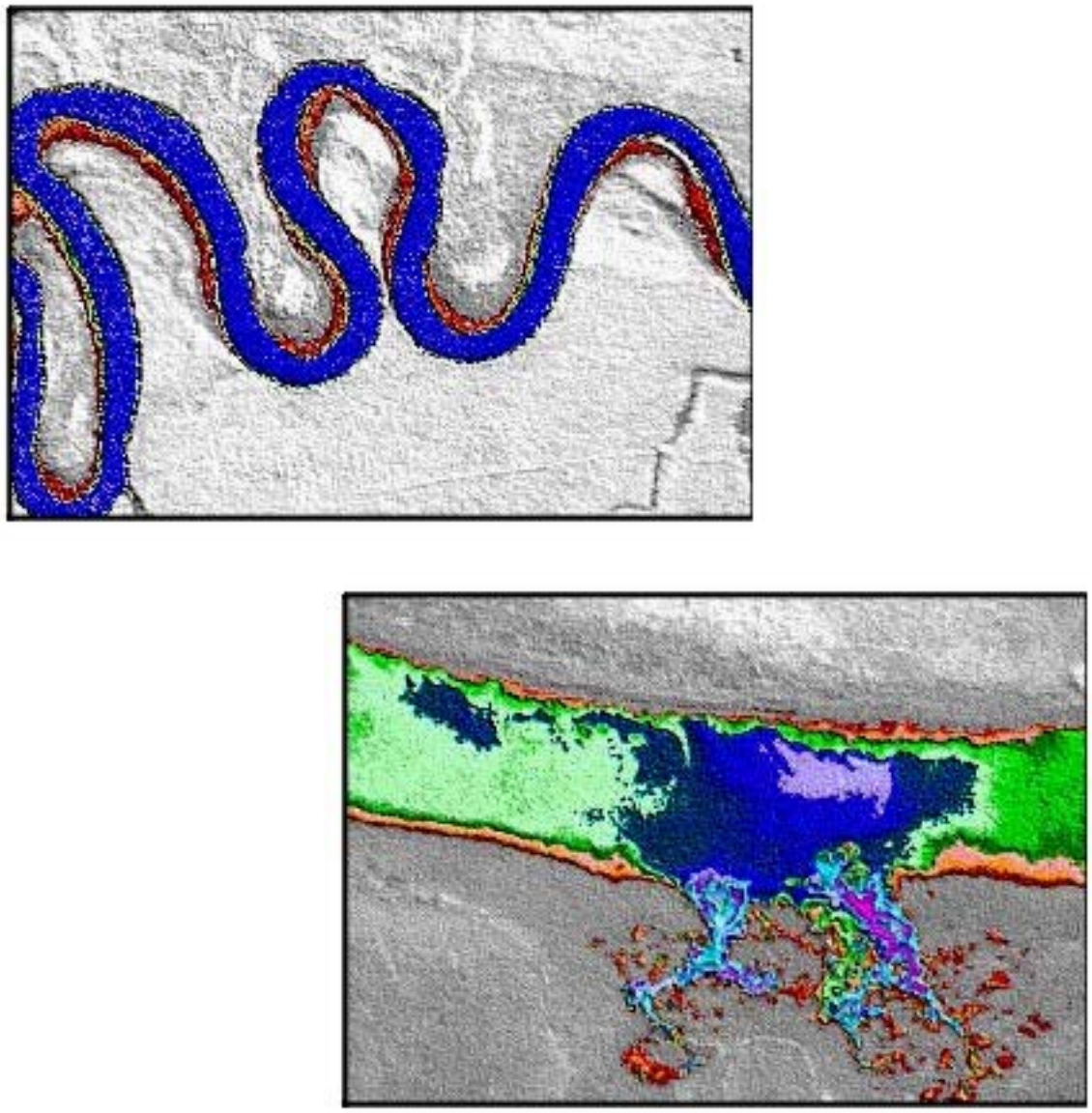


Figure - 2.13. *FLIR derived surface temperatures for the Williamson River. Upper image displays highly sinuous channel in low gradient valley upstream from Klamath Marsh. Lower image displays spring and groundwater inflow and cooling influence on mainstem directly below Klamath Marsh.*

2.2.1 Overview – GIS and Remotely Sensed Data

A wealth of spatial data has been developed for the Upper Klamath Lake Drainage. This report relies extensively on GIS and remotely sensed data. Water quality issues in the Upper Klamath

Lake Drainage are interrelated, complex and spread over thousands of square miles within the drainage. The TMDL analysis strives to capture these complexities using the highest resolution data available. Some of the GIS data used to develop this report are listed in the table below along with the application for which it was used.

Table 2-3. Spatial Data and Application

Spatial Data	Application
10-Meter Digital Elevation Models (DEM)	• Measure Valley Morphology • Measure Topographic Shade Angles
Aerial Imagery - Digital Orthophoto Quads and Rectified Aerial Photos	• Map Near Stream Land Cover • Map Channel Morphology • Map Roads, Development, Structures
FLIR Temperature Data	• Measure Surface Temperatures • Develop Longitudinal Temperature Profiles • Identify Subsurface Hydrology, Groundwater Inflow, Springs
Water Rights Information System (WRIS) and Points of Diversion (POD) Data	• Map locations and estimate quantities of water withdrawals

2.2.2 10-Meter Digital Elevation Model (DEM)

DEM data are used in this analysis to:
- *Delineate drainage area,*
- *Sample stream elevation,*
- *Sample topographic shade.*

The Digital Elevation Model (DEM) data files are representations of cartographic information in a raster form. DEMs consist of a sampled array of elevations for a number of ground positions at regularly spaced intervals. The U.S. Geological Survey, as part of the National Mapping Program, produces these digital cartographic/geographic data files. DEM grid data is rounded to the nearest meter for ten-meter pixels. DEMs are used to determine stream elevation, stream gradient, valley gradient, valley shape/landform and topographic shade angles.

2.2.3 Aerial Imagery - Digital Orthophoto Quads and Rectified Aerial Photos

Aerial imagery is used in this analysis to:
- *Map stream features such as stream position, channel edges and wetted channel edges,*
- *Map near stream vegetation,*
- *Map instream structures such as dams, weirs, unmapped diversions/withdrawals, etc.*

A digital orthophoto quad (DOQ) is a digital image of an aerial photograph in which displacements caused by the camera angle and terrain have been removed. In addition, DOQs are projected in map coordinates combining the image characteristics of a photograph with the geometric qualities of a map. The standard digital orthophoto is a black-and-white with one-meter pixels covering a USGS quarter quadrangle.

Rectified aerial photos can be produced by scanning aerial photos into a computer and adjusting for displacements caused by terrain and/or camera angle. Rectified aerial photos can produce extremely high resolution (less than one-meter) and multi-spectral (color) imagery. DOQs and rectified aerial photographs are used to map streams, delineate near stream vegetation and to identify unmapped features such as diversions, small dams, etc.

2.2.4 WRIS and POD Data - Water Withdrawal Mapping

WRIS and POD Data are used in this analysis to:

- *Map stream instream diversions/withdrawals,*
- *Associate an estimated flow rate to each diversion/withdrawal.*

The Oregon Water Resources Department (OWRD) maintains the Water Rights Information System (WRIS). WRIS is a database used to monitor information related to water rights. A separate database tracks points of diversions (POD). These two databases were linked by ODEQ to map the locations of diversions, rates of water use and types of water use in the Upper Klamath Lake drainage (see **Figure 2-14**). Consumptive use was estimated using these data and incorporated in developing mass balance flow profiles in the Williamson River and Sprague River subbasins.

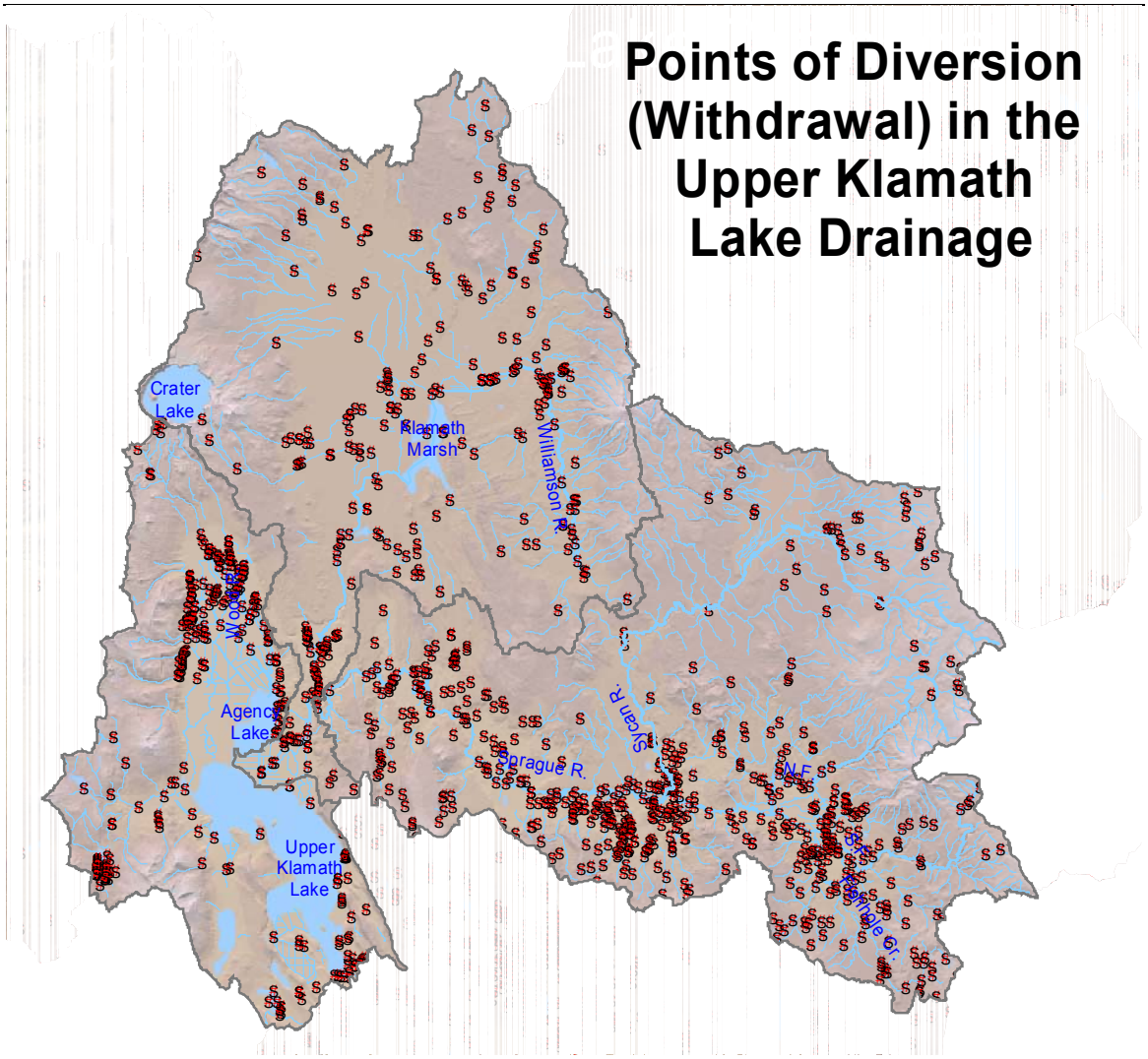


Figure 2-14*. Mapped points of diversion in the Upper Klamath Lake Drainage derived from the WRIS and POD databases (OWRD data, ODEQ database programming and mapping).*

2.2.5 FLIR Temperature Data

FLIR temperature data are used in this analysis to:

- *Develop continuous spatial temperature data sets,*
- *Calculate longitudinal heating profile/gradients,*
- *Visually observe complex distributions of stream temperatures at a large landscape scale,*
- *Map/Identify significant thermal features,*
- *Develop mass balances,*
- *Validate simulated stream temperatures.*

FLIR thermal imagery measures the temperature of the outermost portions of the bodies/objects in the image (i.e., ground, riparian vegetation, stream). The bodies of interest are opaque to longer wavelengths and there is little, if any, penetration of the bodies.

FLIR data is remotely sensed from a sensor mounted on a helicopter that collects digital data directly from the sensor to an on-board computer at a rate that insures the imagery maintains a continuous image overlap of at least 40%. The FLIR detects emitted radiation at wavelengths from 8-12 microns (long-wave) and records the level of emitted radiation as a digital image across the full 12-bit dynamic range of the sensor. Each image pixel contains a measured value that is directly converted to a temperature. Each thermal image has a spatial resolution of less than one-half meter/pixel. Visible video sensor captures the same field-of-view as the FLIR sensor. GPS time is encoded on the recorded video as a means to correlate visible video images with the FLIR images during post-processing.

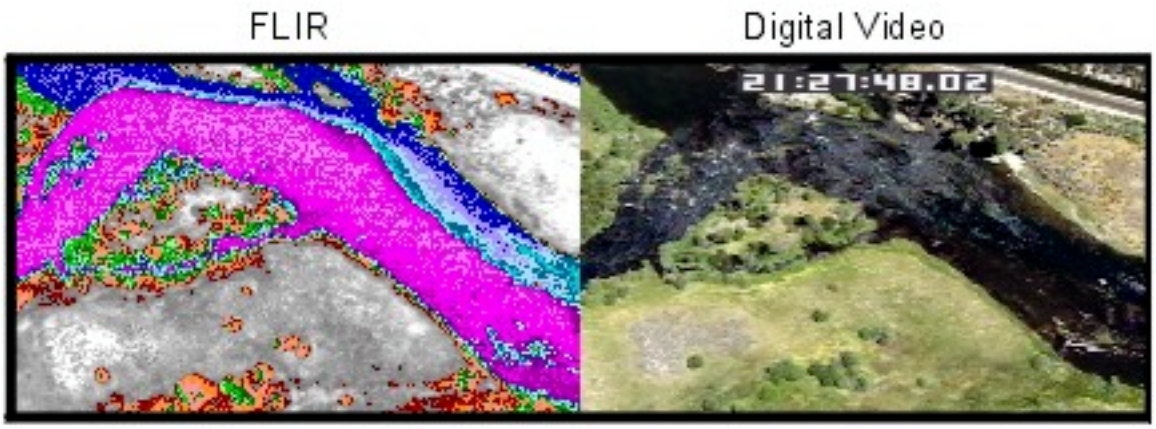


FLIR Equiped helicopter

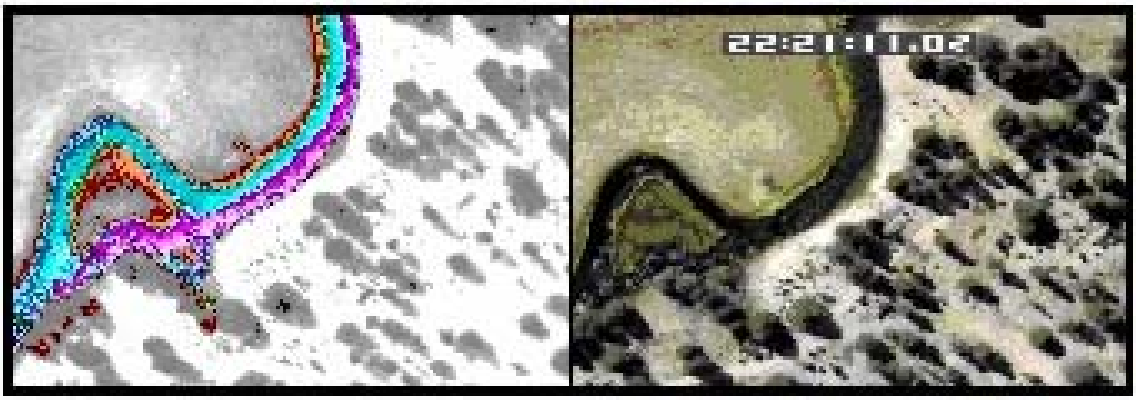
Data collection is timed to capture maximum daily stream temperatures, which typically occur between 14:00 and 18:00 hours. The helicopter is flown longitudinally over the center of the stream channel with the sensors in a vertical (or near vertical) position. In general, the flight altitude is selected so that the stream channel occupies approximately 20-40% of the image frame. A minimum altitude of approximately 300 meters is used both for maneuverability and for safety reasons. If the stream splits into two channels that cannot be covered in the sensor's field of view, the survey is conducted over the larger of the two channels.

In-stream temperature data loggers (Onset Stowaways or VEMCOs) are distributed in each subbasin prior to the survey to ground truth (i.e. verify the accuracy) the radiant temperatures measured by the FLIR. FLIR data can be viewed as GIS point coverages or FLIR imagery.

Direct observation of spatial temperature patterns and thermal gradients is a powerful application of FLIR derived stream temperature data. Thermally significant areas can be identified in a longitudinal stream temperature profile and related directly to specific sources (i.e. water withdrawal, tributary confluence, land cover patterns, etc.). Areas with stream water mixing with subsurface flows (i.e. hyporheic and inflows) are apparent, and often dramatic, in FLIR data. Thermal changes captured with FLIR data can be quantified as a specific change in stream temperature or a stream temperature gradient that results in a temperature change over a specified distance.



Confluence of Sprague River (Top Left) with the Williamson River (Left Middle)



Wickiup Spring - Williamson River mile 79.8.

FLIR Temperature Scale (°F)



Figure 2.15. Examples of FLIR derived surface temperatures for the Williamson River and Sprague Rivers.

2.2.5.1 Williamson River FLIR Derived Longitudinal Heating and Imagery

Williamson River longitudinal temperatures were sampled using forward looking infrared radiometry (FLIR) on August 4, 1999 between 2:19 PM and 3:25 PM. Temperature data sampled from the FLIR imagery reveals a spatial pattern that is variable due to localized high rates of stream heating, numerous flow withdrawals, large contributions of subsurface flow and tributary mixing. For discussion purposes, the Williamson is broken into an upper section (river miles 56.0 to 86.5) above Klamath Marsh and lower section (river miles 0.0 to 42.0) below Klamath Marsh. **Figure 2-16** displays a graphic of FLIR-sampled temperatures for the Williamson River. The longitudinal temperature profile for the Williamson River is presented in **Figure 2-17**. **Images Williamson A-1** through **A-10** depict FLIR and digital video imagery for selected areas of interest.

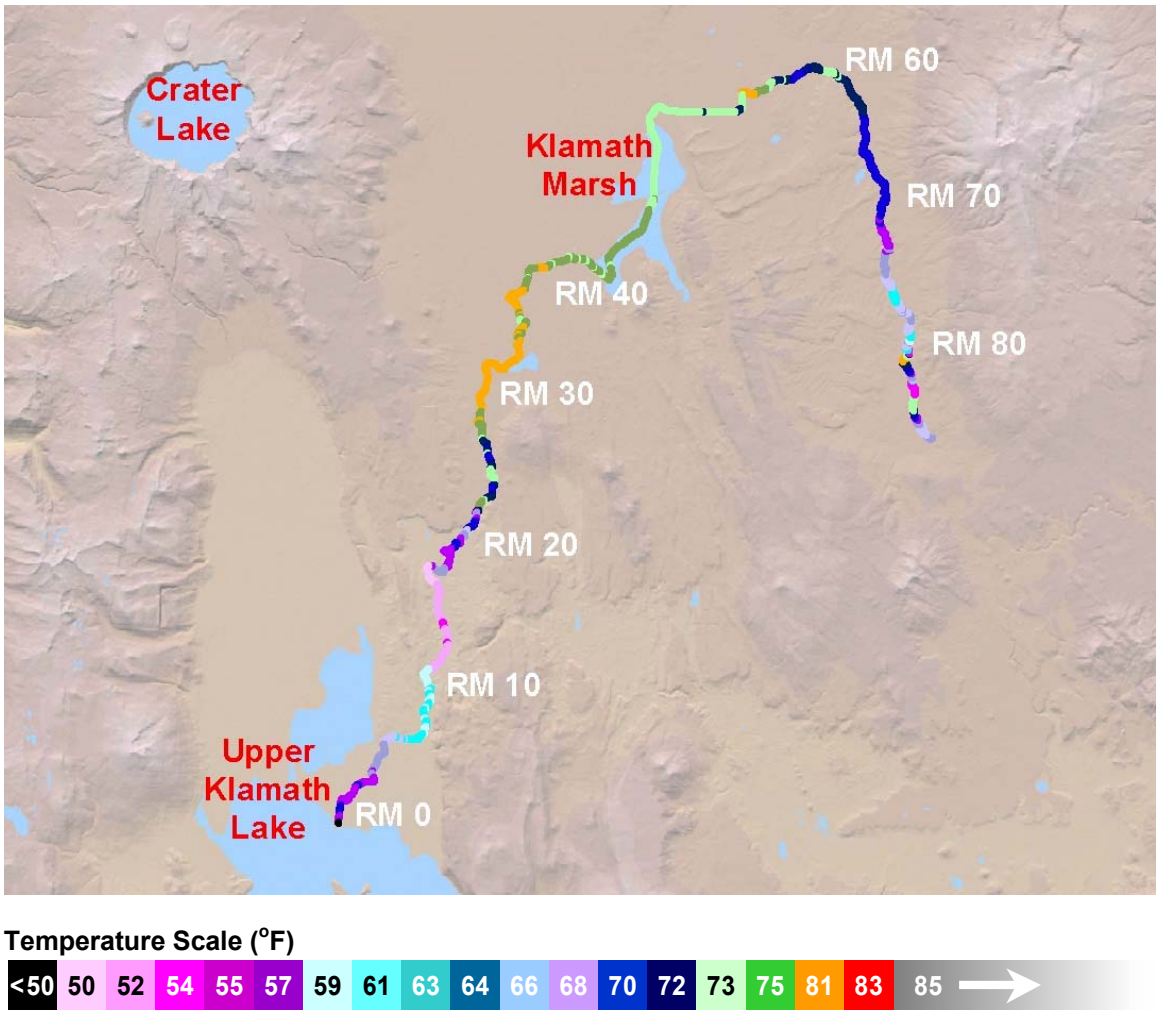


***Figure 2-16**. Williamson River Sampled FLIR Temperatures*

Upper Williamson River sampled temperatures suggest variable spatial distributions (55°F to 77°F), with extremely localized cooler areas associated with springs/groundwater inflow. The upper Williamson River originates from a series of springs that frequently moderate a high stream heating longitudinal gradient (stream heating longitudinal gradients in the uppermost six river miles are between 6°F and 8°F per mile). These high rates of heating are the result of low levels of stream shade, major diversions of instream flow, impoundments and channel modifications.

Two major springs (Williamson Spring - river mile 82.3 and Wickiup Spring - river mile 80.5) cool mainstem temperatures and add stream flow volume. Downstream from Wickiup Spring, the longitudinal gradient of stream heating is moderated (0.5°F to 1.0°F per mile). Major stream flow diversions occur at river mile 58.1, reducing instream flows and causing a corresponding increase in the longitudinal heating gradient (3°F per mile) which continues to Klamath Marsh (approximately river mile 56.0).

The lower Williamson spatial distribution of sampled temperatures is also variable (i.e., 47°F to 80°F), where the warmest temperatures occur directly below Klamath Marsh and the coolest temperatures are associated with springs and groundwater inflow. The lower Williamson River spatial temperature pattern is complex and unique. Riparian/channel conditions, topographic changes, groundwater/spring inflows, tributary mixing and major flow diversions create complex and variable spatial temperature patterns.

Surface water draining from Klamath Marsh is warm (i.e., 75°F to 80°F). Low gradient sinuous channels characterize river miles 28.8 to 42.0, where the longitudinal heating gradient is roughly 0.5°F per mile. It should be noted that temperatures sampled in this river reach are considered very warm and well above levels deemed acceptable for salmonids. Flow diversions and natural bedrock outcroppings create backwater low flow velocity reaches where some stream stratification is observed.

The lower Williamson River then enters a canyon with high gradient reaches, characterized by high stream flow velocities, spring inflows and mixed conifer/hardwood riparian structure. Longitudinal cooling occurs throughout this reach at roughly 1.5°F per mile. Spring Creek (river mile 15.6) significantly cools the mainstem. The Sprague River (river mile 10.5) increases mainstem temperature by roughly 5°F. Lower Williamson River reaches flow through a highly impacted area with relatively simple channels and little longitudinal temperature variability. Stream warming is more pronounced downstream from a series of significant flow withdrawals in the lower seven river miles. Stream warming gradients are roughly 1°F per mile in the lower seven miles of the Williamson River.

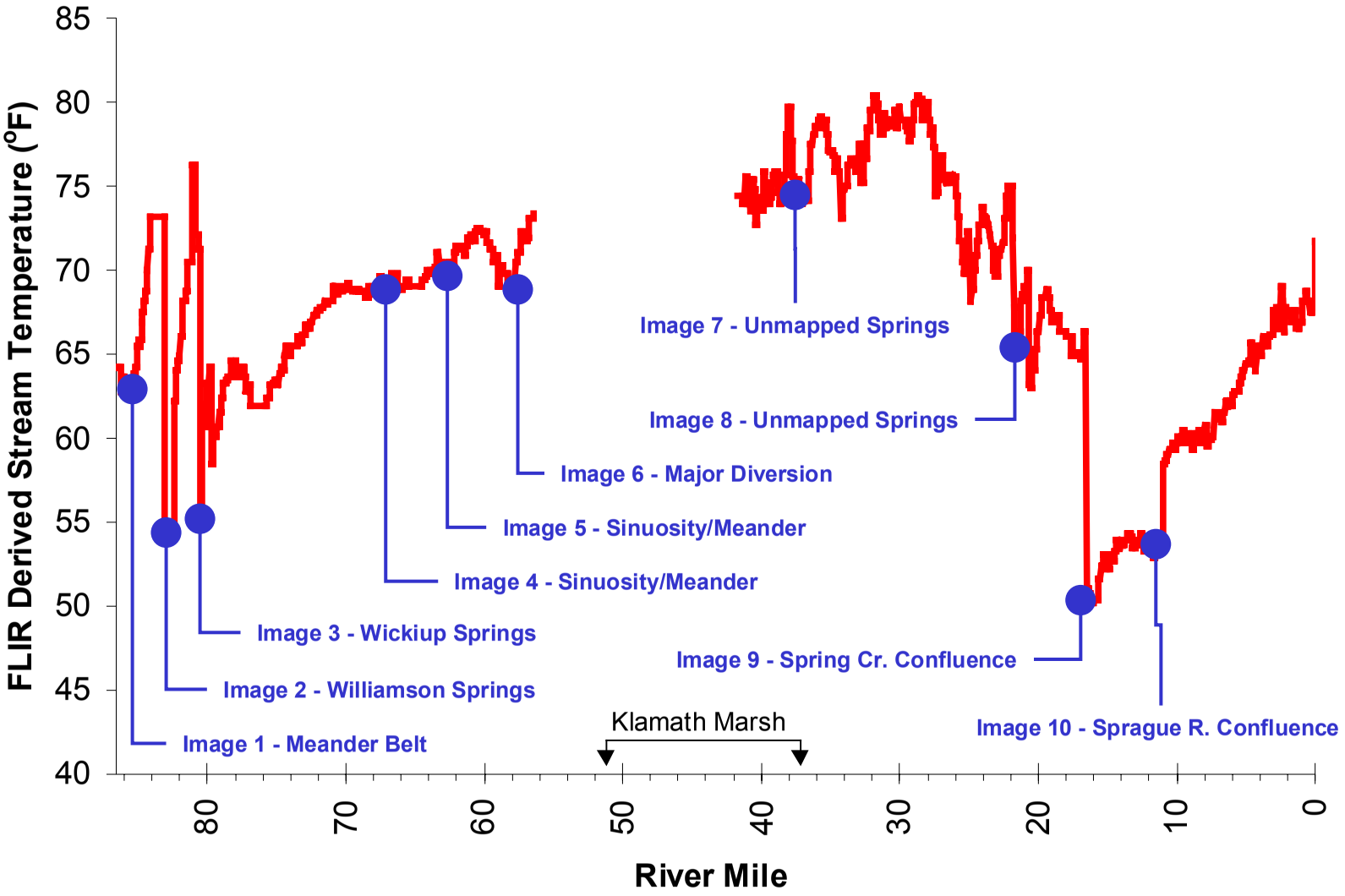
Summary of Selected FLIR Imagery - Williamson River

- **Williamson - Image 1**. Upper Williamson River - Meander Belt with Partial Cutoff Developing - River Miles 85.92 to 85.35. This image demonstrates floodplain hydrologic connectivity in a highly sinuous stream channel. Between meander belts, partial overland and subsurface flow patterns are observed with FLIR imagery. Channel migration is an important component of low gradient and highly sinuous stream channels. This image depicts a natural and healthy process that serves to maintain complex channel morphology.
- **Williamson - Image 2**. Upper Williamson River - Confluence of Williamson River and Williamson Springs - River Miles 82.41 to 82.18. Williamson Springs increases stream flow and dramatically cools mainstem temperatures.
- **Williamson - Image 3**. Upper Williamson River - Confluence of Williamson River and Wickiup Springs - River Miles 80.41 - 80.65. Wickiup Springs consists of a series of points laterally positioned along the stream channel that contribute cold subsurface inflow. A large plume of cool water is delivered to the stream that reduces stream temperatures by 20+°F in the longitudinal direction.
- **Williamson - Image 4**. Upper Williamson River - Sinuosity and Initiation of a Meander Cut Off - River Miles 66.90 to 66.39. This image shows a highly sinuous river reach with channel migration. Additionally, instream woody debris is initiating a meander cut off.
- **Williamson - Image 5**. Upper Williamson River - Sinuosity and Evidence of Stream Straightening - River Miles 63.10 to 62.45. This upper Williamson River reach is highly

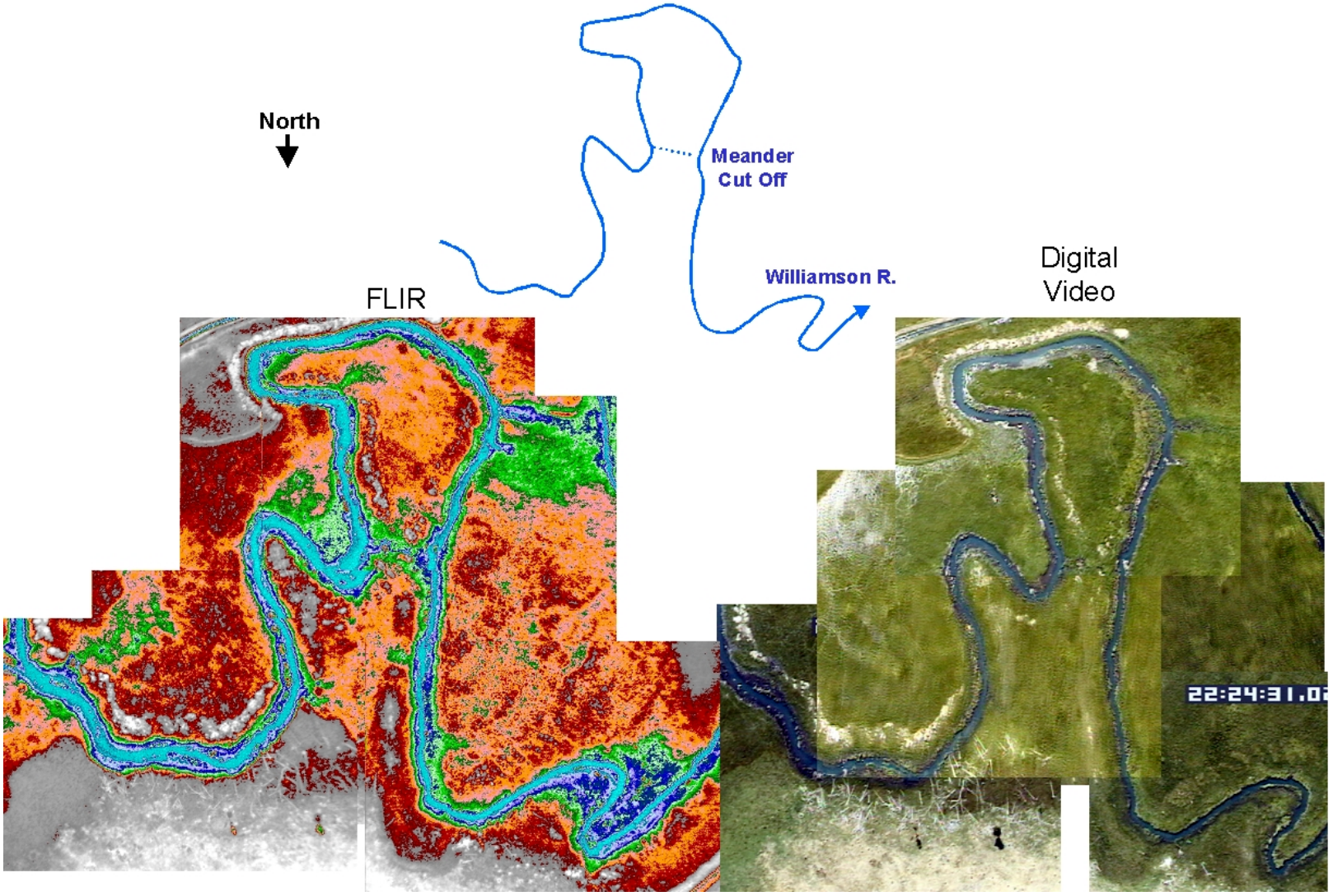
sinuous. However, evidence of stream straightening is apparent when considering visible abandoned channel meanders. Many of these meander belts have been discontented from the stream channel, resulting in reduced sinuosity (i.e., stream channel simplification). As a stream channel straightens, stream length is reduced and stream gradients are increased. A consequence of stream straightening is increased stream power that translates to higher shear stress along stream banks and induces stream bank erosion/retreat and/or downcutting. Such conditions are often compounded by near stream land cover disturbance/removal that decreases soil cohesion, decreases rooting strength, increases stream bank sloughing and decreases floodplain roughness. While a degree of natural migration of stream channels of this type commonly occurs, this image suggests that stream straightening is occurring within this river reach.

- **Williamson - Image 6**. Upper Williamson River - Major Irrigation Diversion and Associated Stream Warming - River Miles 56.53 to 56.20. Decreases in stream flow associated with this irrigation diversion induce a stream warming longitudinal gradient of 3°F per mile. Recall that stream temperature change is inversely proportional for flow volume. As flow volume decreases, temperature variability increases.
- **Williamson - Image 7**. Lower Williamson River - Unmapped Spring - River Miles 37.97 to 37.46. Several unmapped springs were detected in the FLIR imagery. This relatively small surface contribution to the mainstem creates a localized reduction in otherwise warm stream volume.
- **Williamson - Image 8**. Lower Williamson River - Unmapped Spring - River Miles 22.09 to 21.57. Additional unmapped springs significantly cool the lower Williamson River. Of particular importance is that these springs reduce stream temperatures to levels that create habitat for salmonids.
- **Williamson - Image 9**. Lower Williamson River - Confluence of Spring Creek and Williamson River - River Miles 16.67 to15.40. Spring Creek adds a large volume of very cold water to the lower Williamson River. The plume associated with Spring Creek extends for nearly 1.5 miles downstream before completely mixing with the mainstem Williamson River. The result is a variable transverse temperature gradient where temperatures can vary 6°F to 8°F across the channel throughout the plume.
- **Williamson - Image 10**. Lower Williamson River - Confluence of Sprague River and Williamson River - River Miles 11.38 to 10.41. The Sprague River warms the lower Williamson River and creates a plume that extends for roughly one quarter mile downstream.

Figure 2-17. Williamson River FLIR Derived Temperatures - August 4, 1999 (2:19 - 3:25 PM)



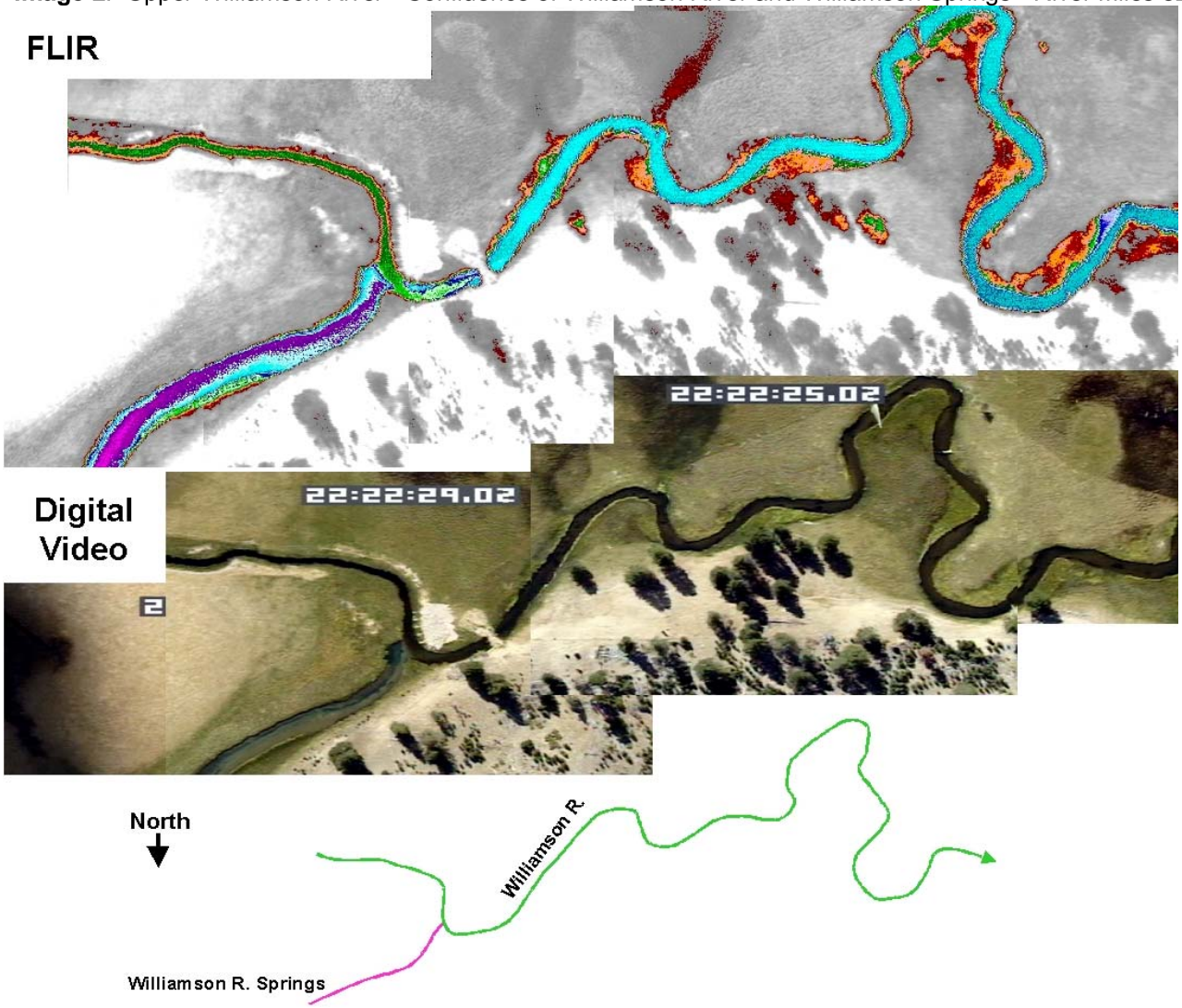
Williamson - Image 1. Upper Williamson River - Meander Belt with Partial Cutoff Developing - River Miles 85.92 to 85.35.



FLIR Derived Temperature (°F) - August 4, 1999 (2:19 - 3:25 PM)



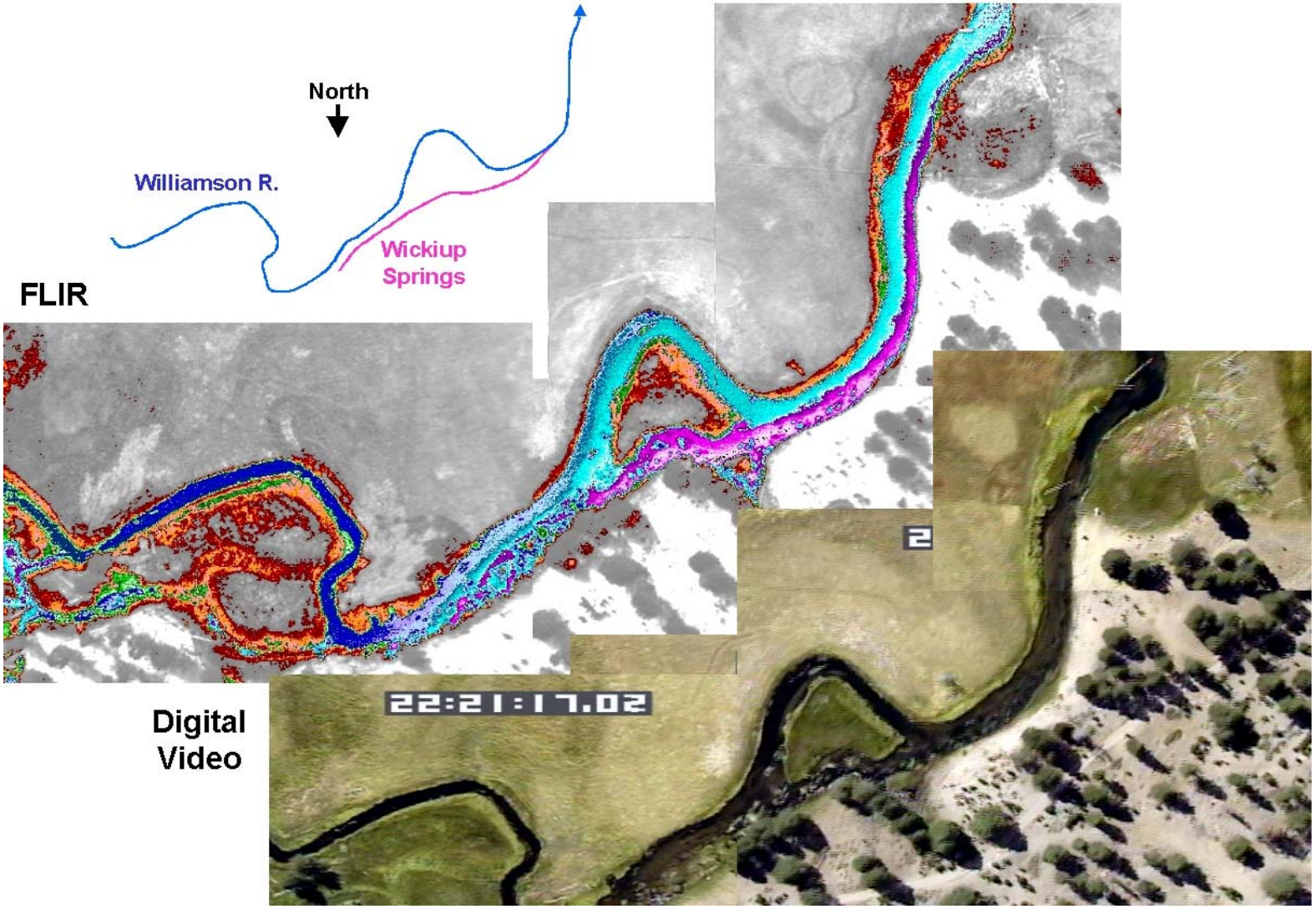
Williamson - Image 2. Upper Williamson River - Confluence of Williamson River and Williamson Springs - River Miles 82.41 to 82.18



FLIR Derived Temperature (°F) - August 4, 1999 (2:19 - 3:25 PM)



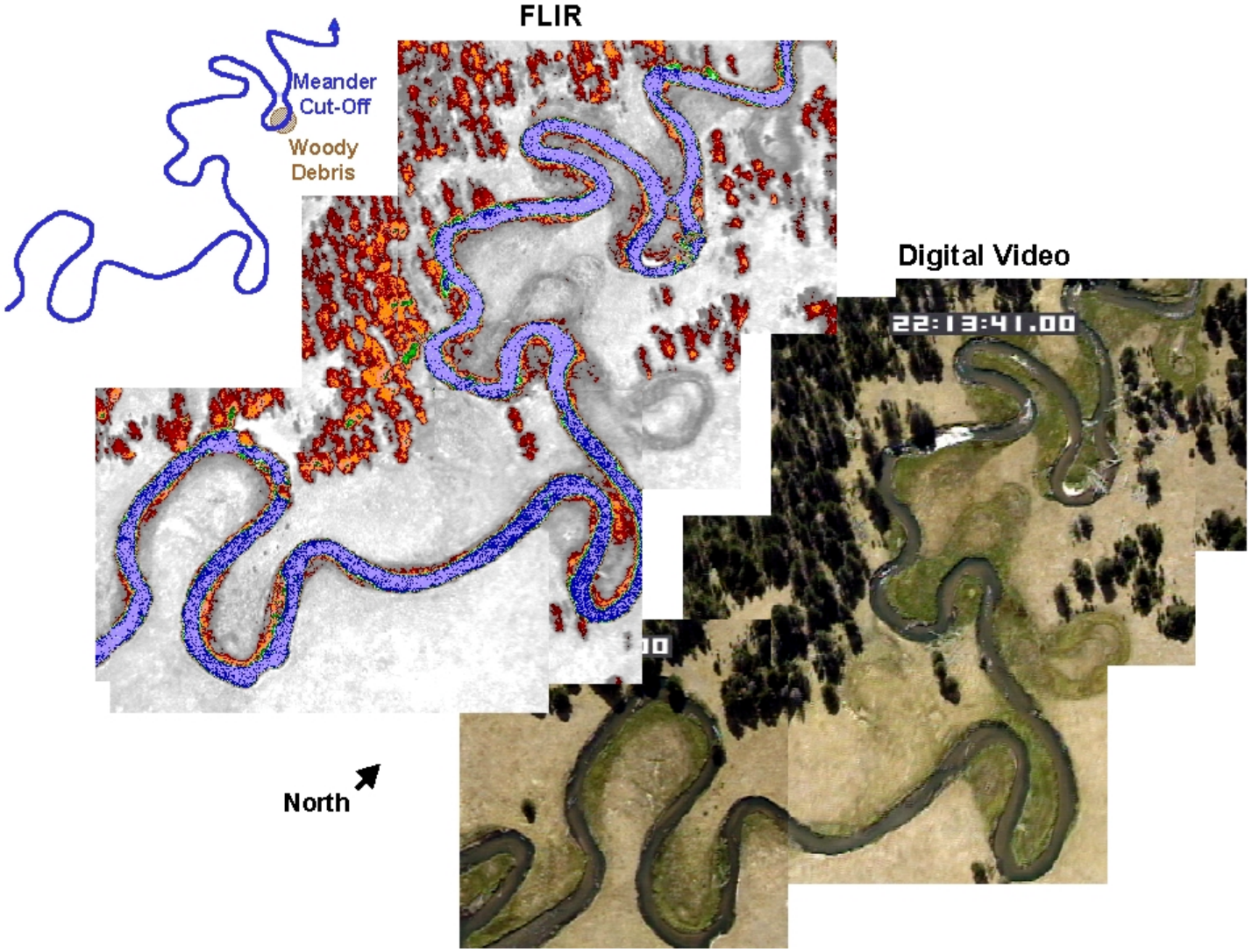
Williamson - Image 3. Upper Williamson River - Confluence of Williamson River and Wickiup Springs - River Miles 80.65 to 80.41



FLIR Derived Temperature (°F) - August 4, 1999 (2:19 - 3:25 PM)



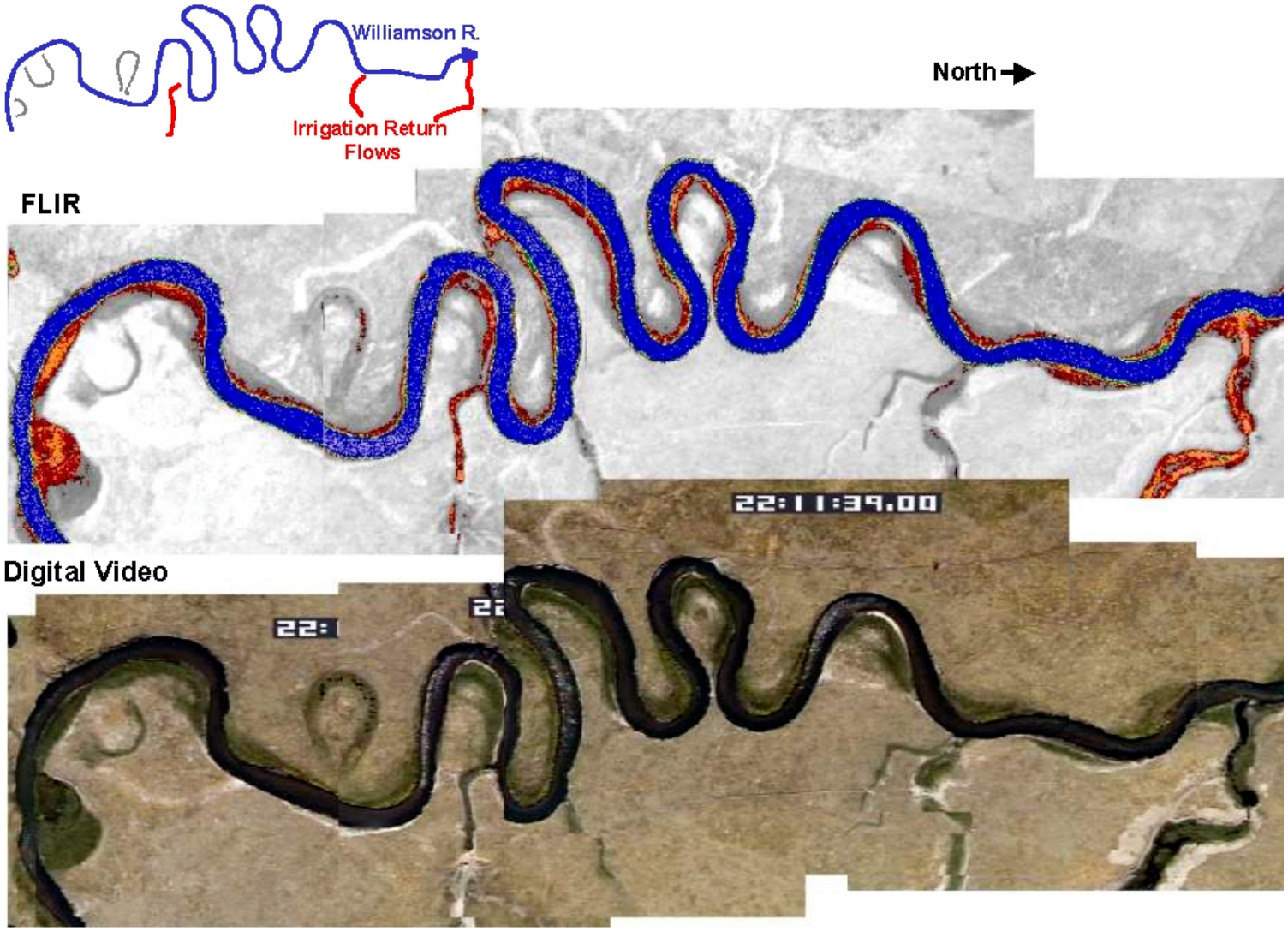
Williamson - Image 4. Upper Williamson River - Sinuosity and Initiation of a Meander Cut Off - River Miles 66.90 to66.39



FLIR Derived Temperature (°F) - August 4, 1999 (2:19 - 3:25 PM)



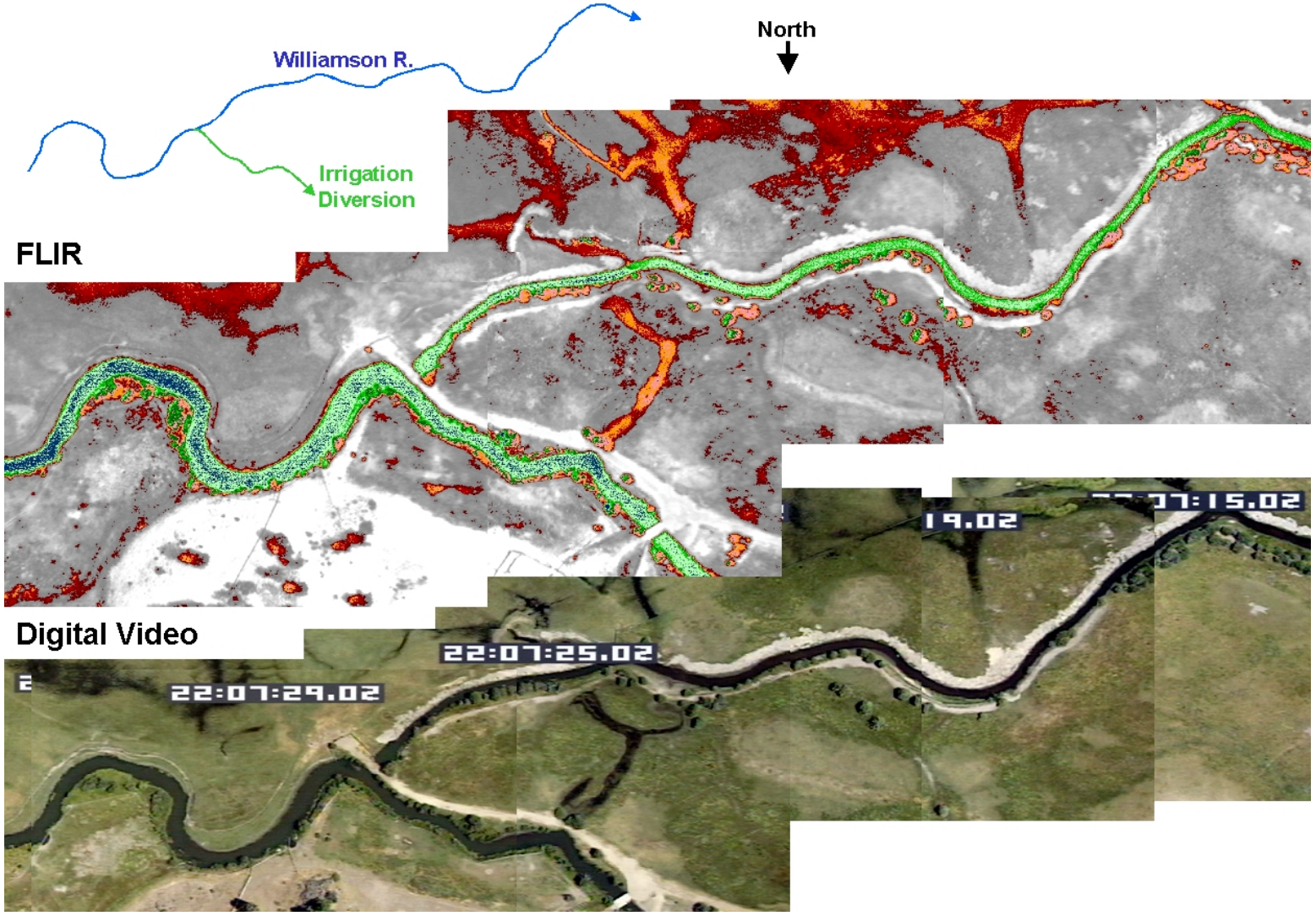
Williamson - Image 5. Upper Williamson River - Sinuosity and Evidence of Stream Straightening - River Miles 63.10 to 62.45



FLIR Derived Temperature (°F) - August 4, 1999 (2:19 - 3:25 PM)



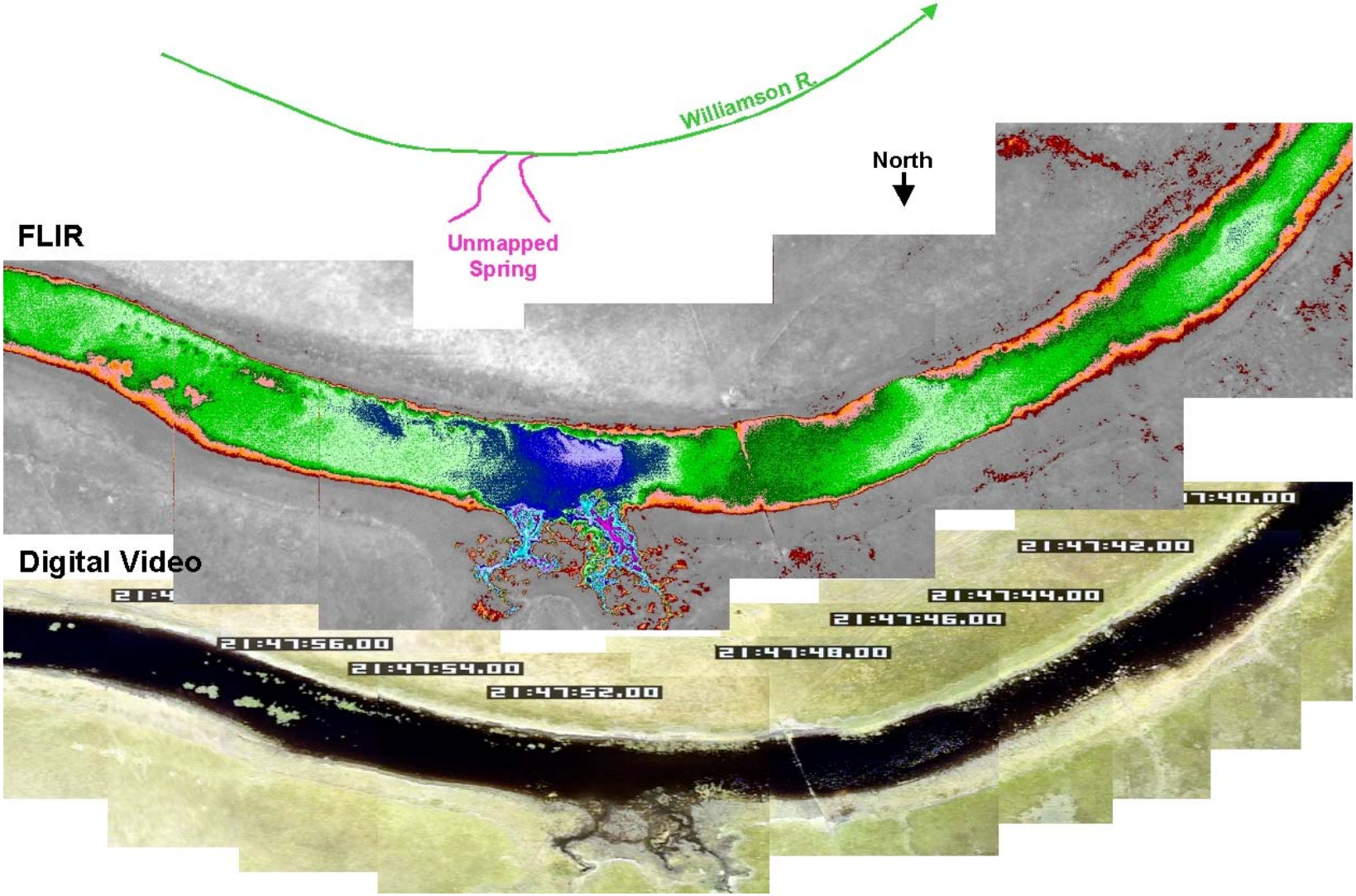
Williamson - Image 6. Upper Williamson River - Major Irrigation Diversion and Associated Stream Warming - River Miles 56.53 to 56.20



FLIR Derived Temperature (°F) - August 4, 1999 (2:19 - 3:25 PM)



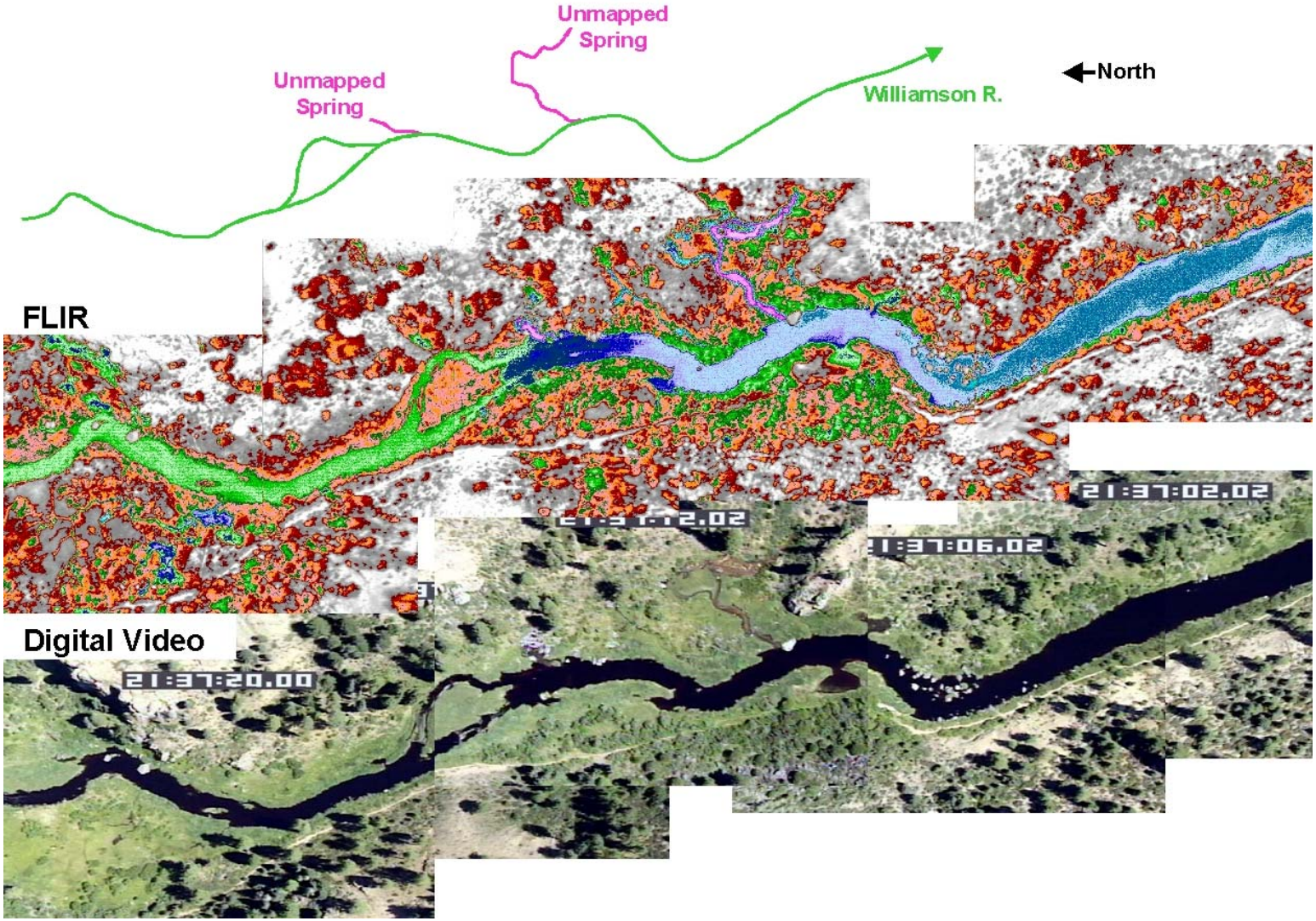
Williamson - Image 7. Lower Williamson River - Unmapped Spring - River Miles 37.97 to 37.46



FLIR Derived Temperature (°F) - August 4, 1999 (2:19 - 3:25 PM)

<50	50	52	54	55	57	59	61	63	64	66	68	70	72	73	75	81	83	85 →

Williamson - Image 8. Lower Williamson River - Unmapped Spring - River Miles 22.09 to 21.57



FLIR Derived Temperature (°F) - August 4, 1999 (2:19 - 3:25 PM)

<50	50	52	54	55	57	59	61	63	64	66	68	70	72	73	75	81	83	85 →

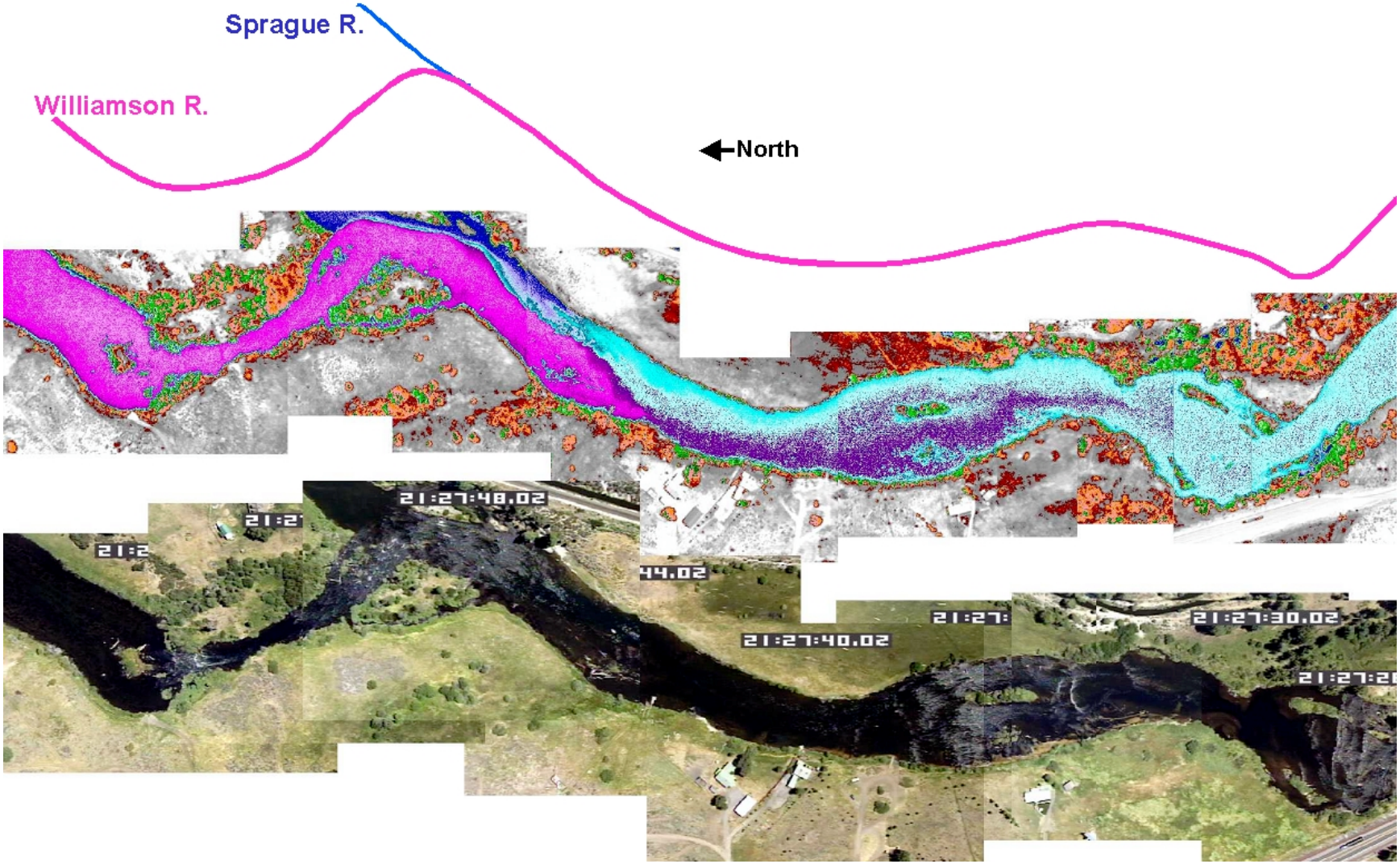
Williamson - Image 9. Lower Williamson River - Confluence of Spring Creek and Williamson River - River Miles 16.67 to 15.40



FLIR Derived Temperature (°F) - August 4, 1999 (2:19 - 3:25 PM)

<50	50	52	54	55	57	59	61	63	64	66	68	70	72	73	75	81	83	85 →

Williamson - Image 10. Lower Williamson River - Confluence of Sprague River and Williamson River - River Miles 11.38 to 10.41



FLIR Derived Temperature (°F) - August 4, 1999 (2:19 - 3:25 PM)



2.2.5.2 Sycan River FLIR Derived Longitudinal Heating and Imagery

Sycan River longitudinal temperatures were sampled using FLIR on August 16, 1999 in two separate helicopter flights. The lower 58.55 river miles were sampled from 2:43 to 3:24 PM, while the upper 12.95 river miles were sampled from 4:53 to 5:02 PM (the helicopter had to land and refuel). The FLIR sensor and day TV camera were turned off over the Sycan Marsh because there was no distinct stream channel to monitor. **Figure 2-18** shows the FLIR flight path – color coded to represent the measured stream temperature.



***Figure 2-18**. Sycan River Sampled FLIR Temperatures*

Headwater Sycan River temperatures in the upper 13 river miles has a longitudinal heating rate of 0.6°F per mile. Through this upper area, small tributaries and some springs help moderate temperature increases with cool mass transfers that cause sudden and temporary stream cooling. Due to the smaller flow volume of the Sycan River in this upper reach, responses to cool water inputs are more dramatic. Likewise, the stream rapidly gains heat a short distance downstream.

The remaining portions of the Sycan River (from the mouth to river mile 58.6) has a stream temperature profile that fluctuates between a low temperature of 60°F and a high of 72°F. At about river mile 54.0, the Sycan River orientation turns to a north/south direction, and the channel widens slightly compared to upstream. This orientation exposes the river to more direct sunlight, which is likely to be one of the factors that accounts for the sharp heating observed between river

miles 50.0 and 54.0. Beginning at approximately river mile 49.0, the Sycan River gradient lessens and the valley begins to widen. A weir at river mile 45.8 creates a marshy backwater, where the Sycan River temperature suddenly drops 6°F. A diversion canal at this weir diverts a large volume of water. Another weir at river mile 44.0 creates more backwater. Below this weir, the Sycan River is channelized as it enters the Sycan Marsh.

Water draining the Sycan Marsh is 70°F. For the next 14 river miles, the stream temperature fluctuates, but there is no distinct heating pattern. An unmapped spring at river 26.8 drops the river temperature from 65°F to 60°F. Two more unmapped springs at about river mile 25.7 further decrease the river temperature. For the next five river miles, temperature climbs steadily and rapidly. Teddy Powers Meadow (river miles 17.4 to 20.2) is a stream heating area with a maximum temperature of 72°F. Temperatures decrease as the river enters a confined canyon until river mile 14, and downstream the temperatures rise again as the river flows in a less confined valley and has a steeper gradient. At about river mile 9.4, the steep gradient suddenly flattens out as the valley opens up. The immediate decrease in gradient causes the river to be deeper and much slower. From river mile 9.4 to the mouth, the river temperatures fluctuate between 66°F and 72°F.

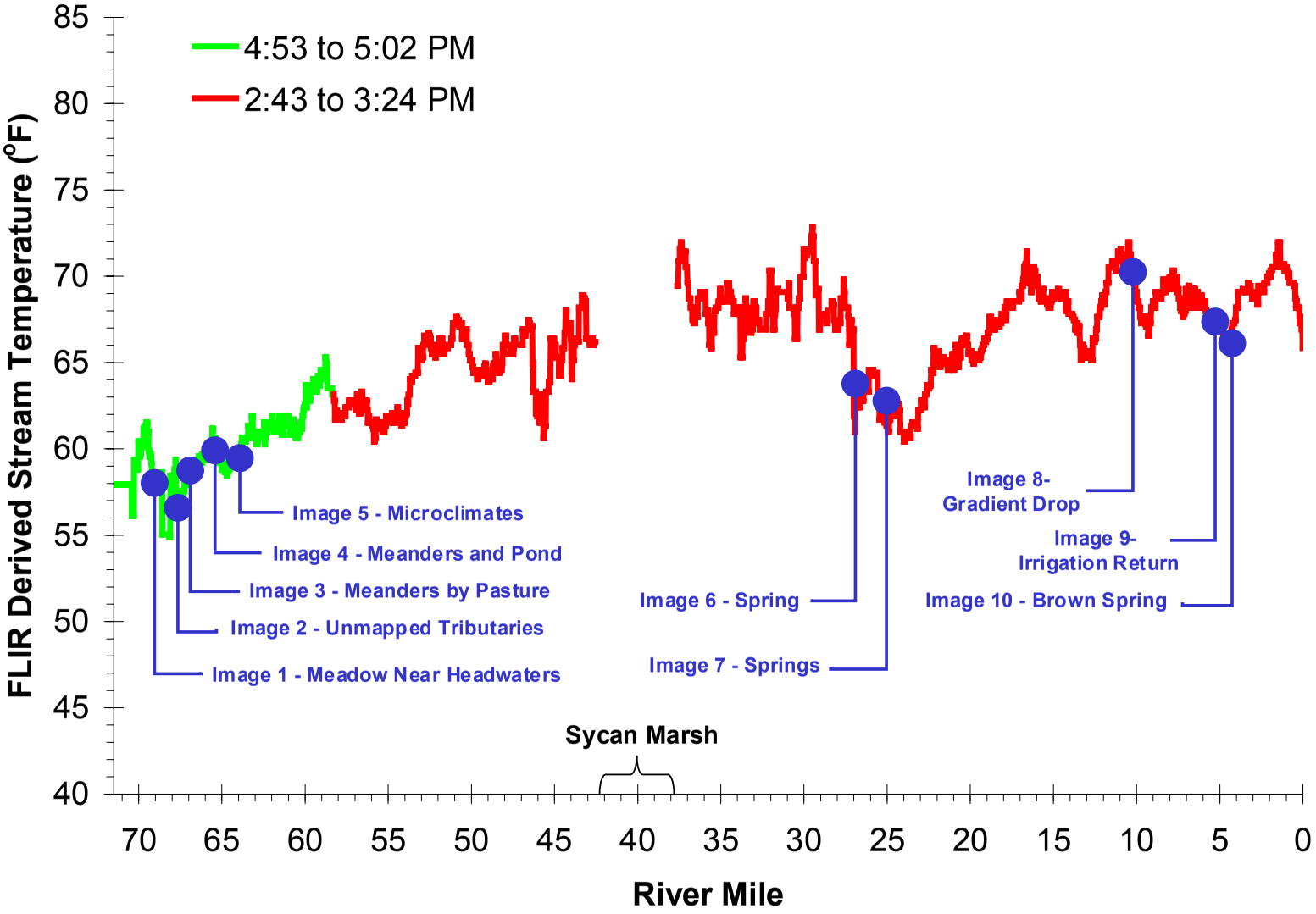
Summary of Selected FLIR Imagery - Sycan River

- **Sycan - Image 1**. Sycan River – Meadow Near Headwaters – River Miles 68.26 to 68.39. Upstream of the road, the Sycan River is under 50°F. It enters the meadow shown and heats to above 50°F in a short distance. The floodplain in this meadow is connected to the river, demonstrated by the cool ground temperatures on all sides of the stream.
- **Sycan - Image 2**. Sycan River - Unnamed Tributaries – River Miles 67.62 to 67.87. On the left and bottom of the image, is land that is grazed. Notice the varying surface temperatures of land cover within the image. Warmer land cover and ground temperatures occur in the grazed areas where woody vegetation and shrubs are noticeably absent. There are two separate tributaries that flow in from the left of the image as well. The lower tributary a cooling influence on the Sycan River, dropping the temperature from 59°F to 57°F.
- **Sycan - Image 3**. Sycan River - Meanders by Pasture – River Miles 67.42 to 66.62. This image displays three distinct microclimates: the warm agricultural field surface, the cool near stream floodplain, and the even cooler zone in the shadows of the trees (pink dotted line). Additionally, there is a stand of trees within the middle of the field that is about 70°F, compared to the above-85°F temperatures of the field. The Sycan River increases from 57°F to 60°F in this reach.
- **Sycan - Image 4**. Sycan River - Meanders by Pond – River Miles 65.34 to 65.49. This forested stretch of the Sycan River remains rather cool. There are several areas along the bank that are 3-4°F cooler than the stream resulting from high shade levels.
- **Sycan - Image 5.** Sycan River – Microclimates – River Miles 64.52 to 64.64. Two microclimates are present in this image: the cooler north-facing hillside and the warmer south-facing hillside. In addition, there are two cool (57°F) patches along the left bank. These cool spots are likely due to high shade levels.
- **Sycan - Image 6**. Sycan River – Unmapped Spring – River Miles 26.74 to 26.83. This unmapped spring contributes a significant volume of 49°F water to the Sycan River, decreasing the river temperatures from about 65°F to 60°F.
- **Sycan - Image 7**. Sycan River – Unmapped Springs – River Miles 25.58 to 25.71. There are two springs on the right bank, which produce cool plumes in the Sycan River and an river temperature decrease from 64.5°F to 61.9°F in this reach.
- **Sycan - Image 8**. Sycan River –Gradient Decrease – River Miles 9.18 to 9.50. This is the point at which the Sycan River reaches the valley bottom with a rather abrupt decrease in the

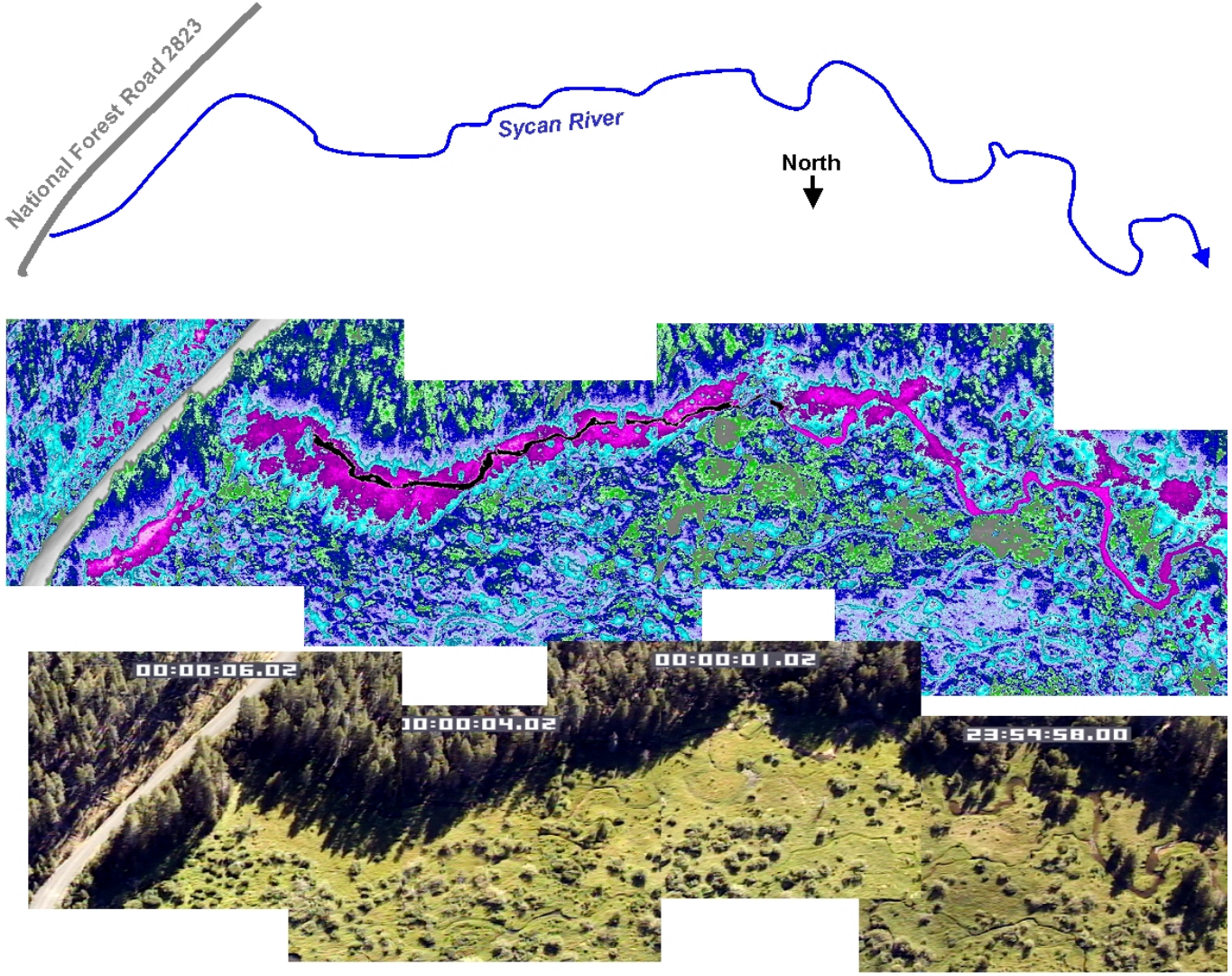
stream gradient. Just downstream of the imagery, the Sycan River is deeper and much slower. This lower gradient continues to the mouth. Stream temperatures fall from 71.6°F to 66.2°F within 0.93 miles from the gradient drop (i.e. -5.8°F per mile).

- **Sycan - Image 9.** Sycan River – Irrigation Return – River Miles 4.73 to 5.04. An agricultural irrigation surface return on the left bank (72.0°F) enters the Sycan River (66.0°F). A small diffuse plume results. The day video image displays a deposit of fine sediments and possible organic material attributed to the irrigation return.
- **Sycan - Image 10**. Sycan River – Brown Spring – River Miles 3.95 to 4.36. In the upper left of the imagery is a small spring on the left bank of the river. Brown Spring enters the Sycan River downstream of this unmapped spring on the right bank. Water from Brown spring is warmed considerably before reaching the Sycan River. Originating one mile from the Sycan River and traveling on the surface through ponds before reaching the Sycan River, the water from Brown Spring is 69.3°F when it reaches the Sycan River.

Figure 2-19. Sycan River FLIR Derived Temperatures - August 16, 1999 (2:43 to 3:24 PM and 4:53 to 5:02 PM)



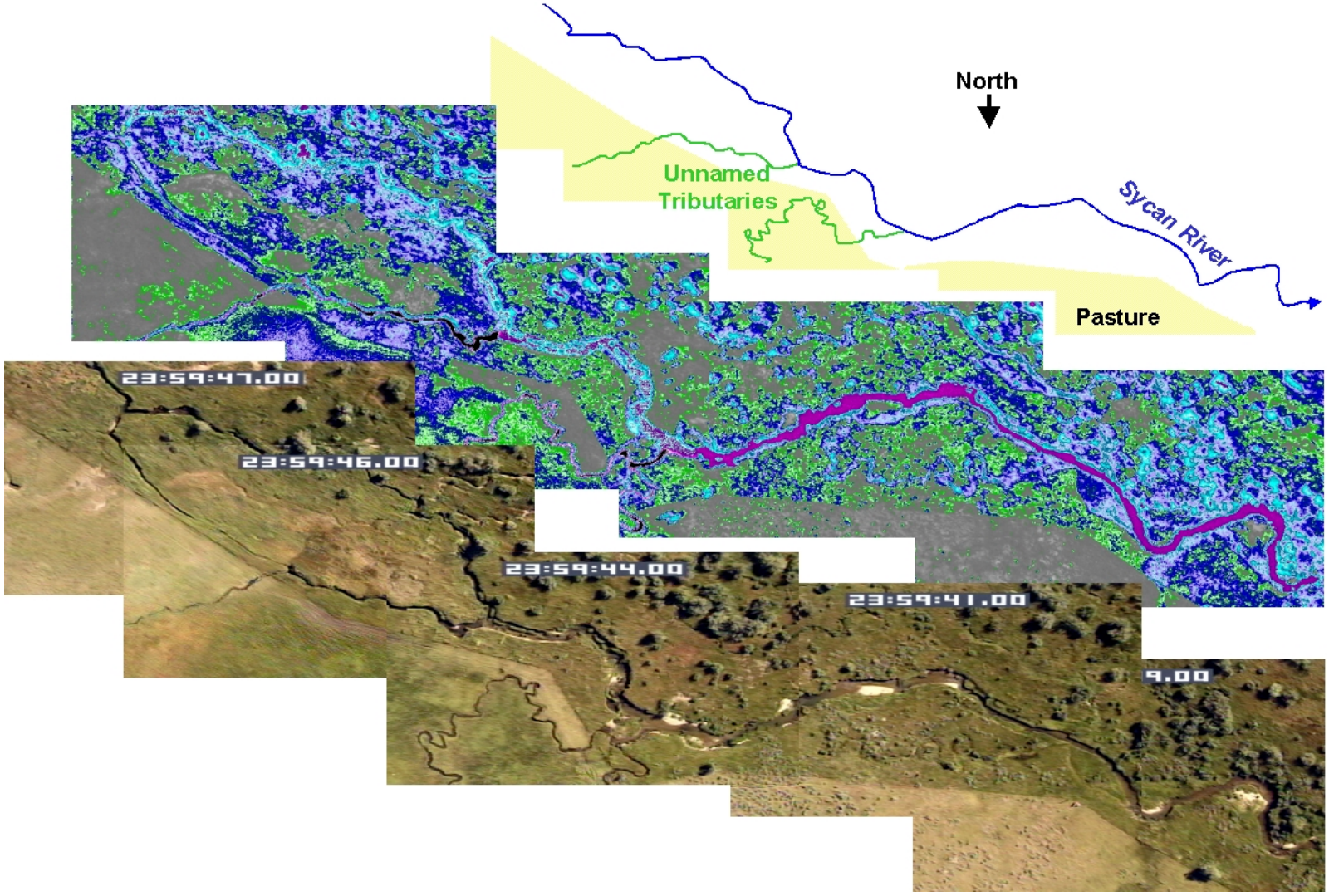
Sycan - Image 1. Sycan River – Meadow Near Headwaters – River Miles 68.26 to 68.39



FLIR Derived Temperature (°F) - August 16, 1999 (2:43 to 3:24 PM and 4:53 to 5:02 PM)



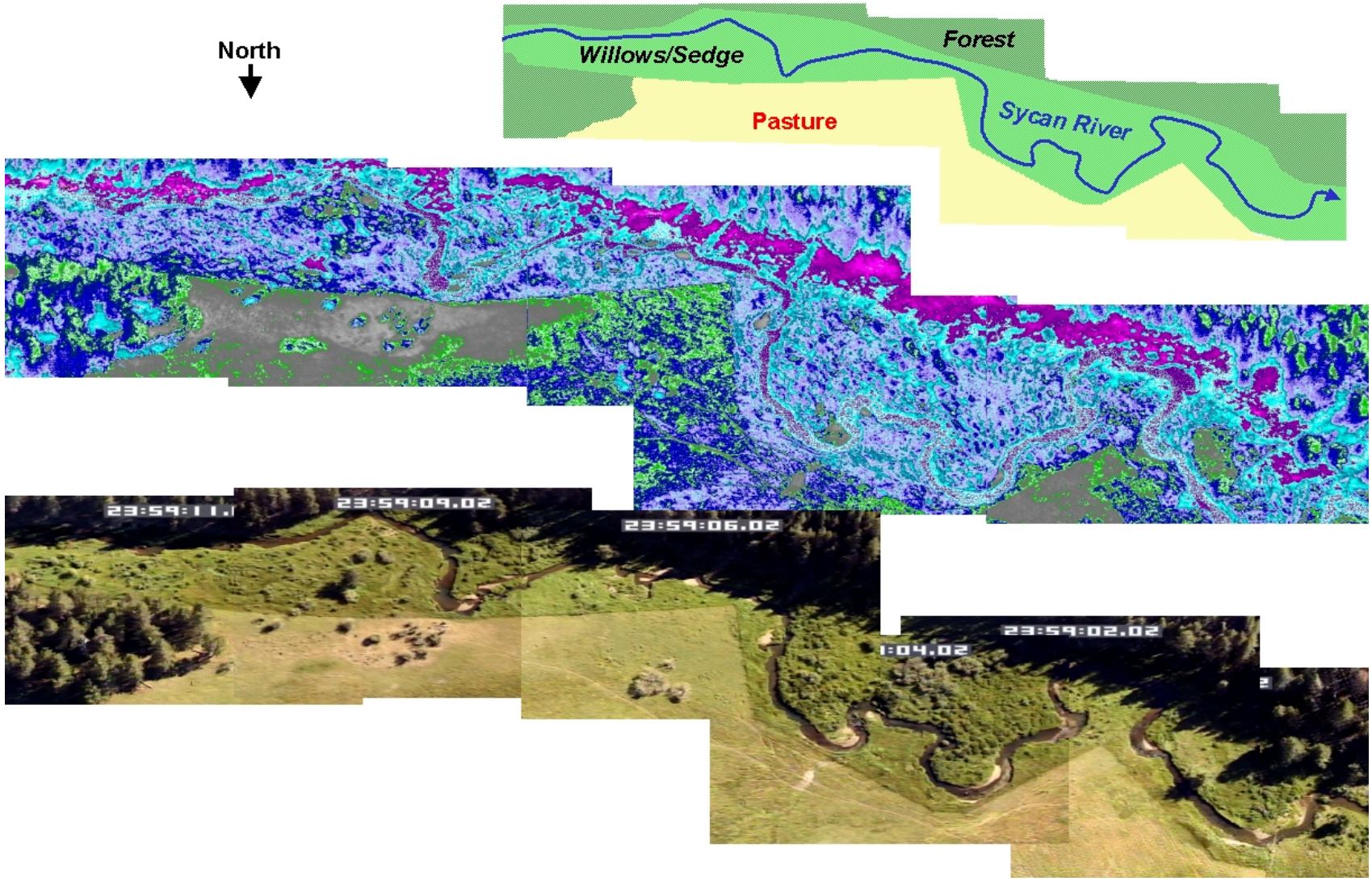
Sycan - Image 2. Sycan River - Unnamed Tributaries – River Miles 67.62 to 67.86



FLIR Derived Temperature (°F) - August 16, 1999 (2:43 to 3:24 PM and 4:53 to 5:02 PM)



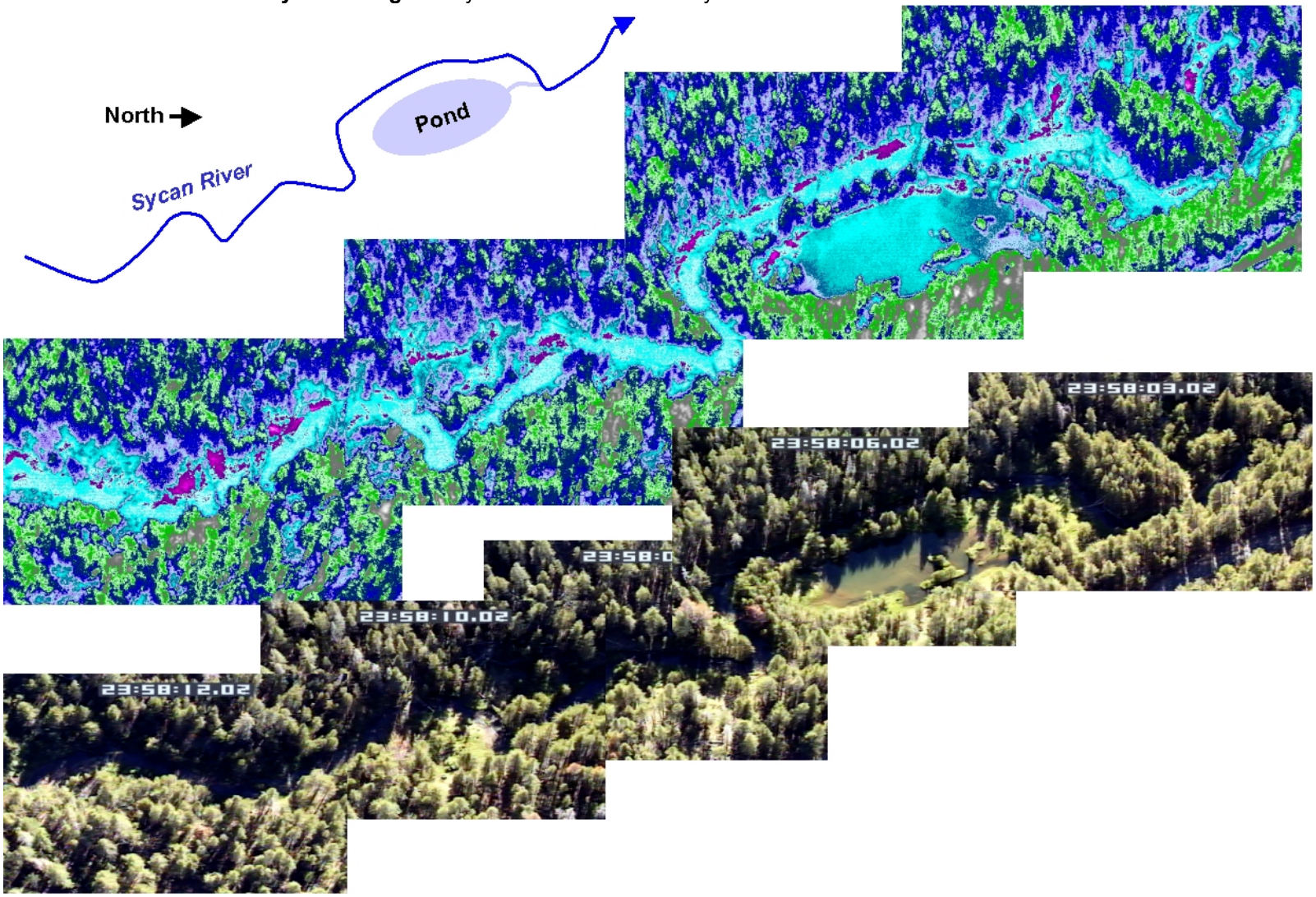
Sycan - Image 3. Sycan River - Meanders by Pasture – River Miles 67.42 to 66.62



FLIR Derived Temperature (°F) - August 16, 1999 (2:43 to 3:24 PM and 4:53 to 5:02 PM)

<50 | 50 | 52 | 54 | 55 | 57 | 59 | 61 | 63 | 64 | 66 | 68 | 70 | 72 | 73 | 75 | 81 | 83 | 85 →

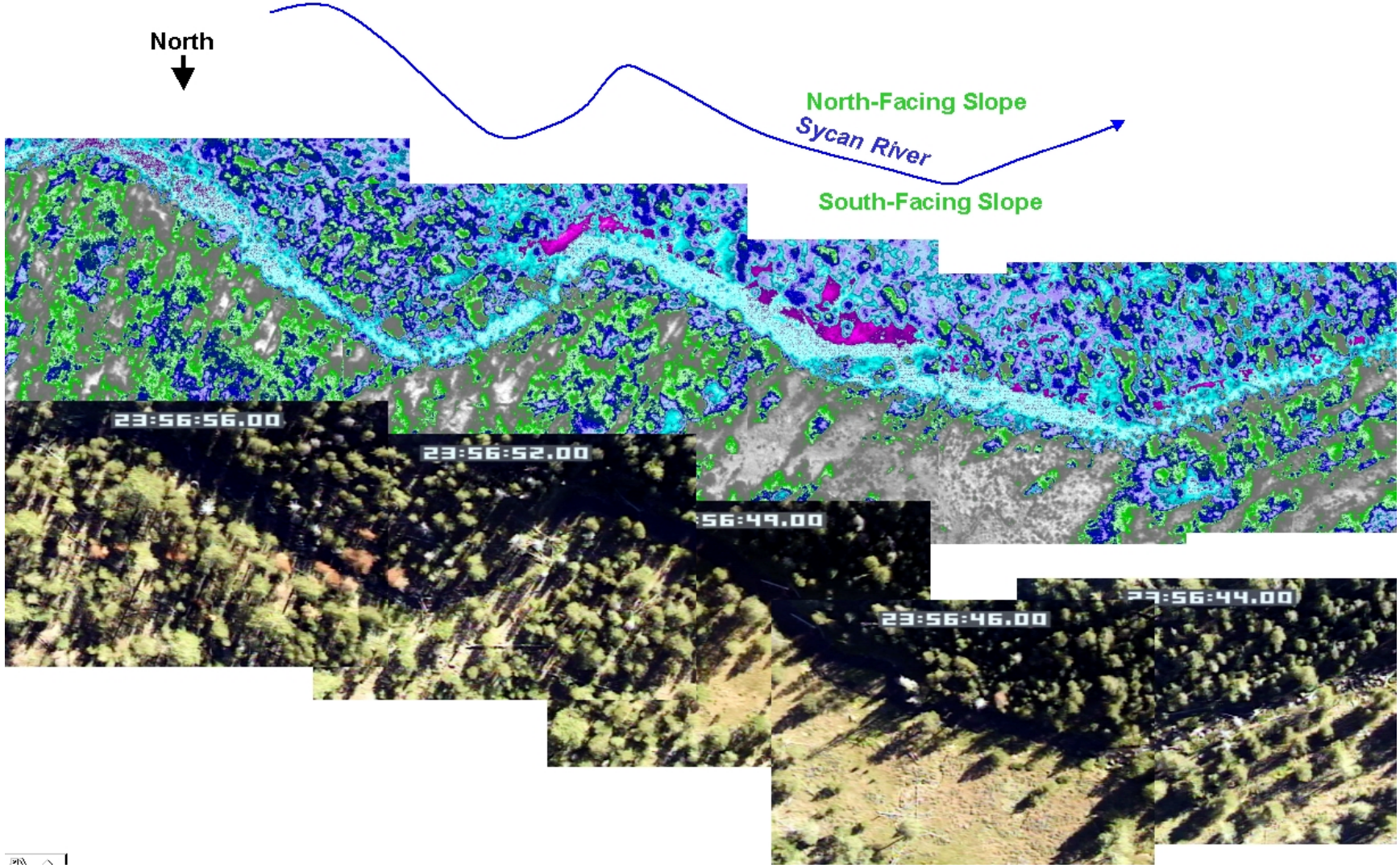
Sycan - Image 4. Sycan River - Meanders by Pond – River Miles 65.34 to 65.49



FLIR Derived Temperature (°F) - August 16, 1999 (2:43 to 3:24 PM and 4:53 to 5:02 PM)

<50 | 50 | 52 | 54 | 55 | 57 | 59 | 61 | 63 | 64 | 66 | 68 | 70 | 72 | 73 | 75 | 81 | 83 | 85 →

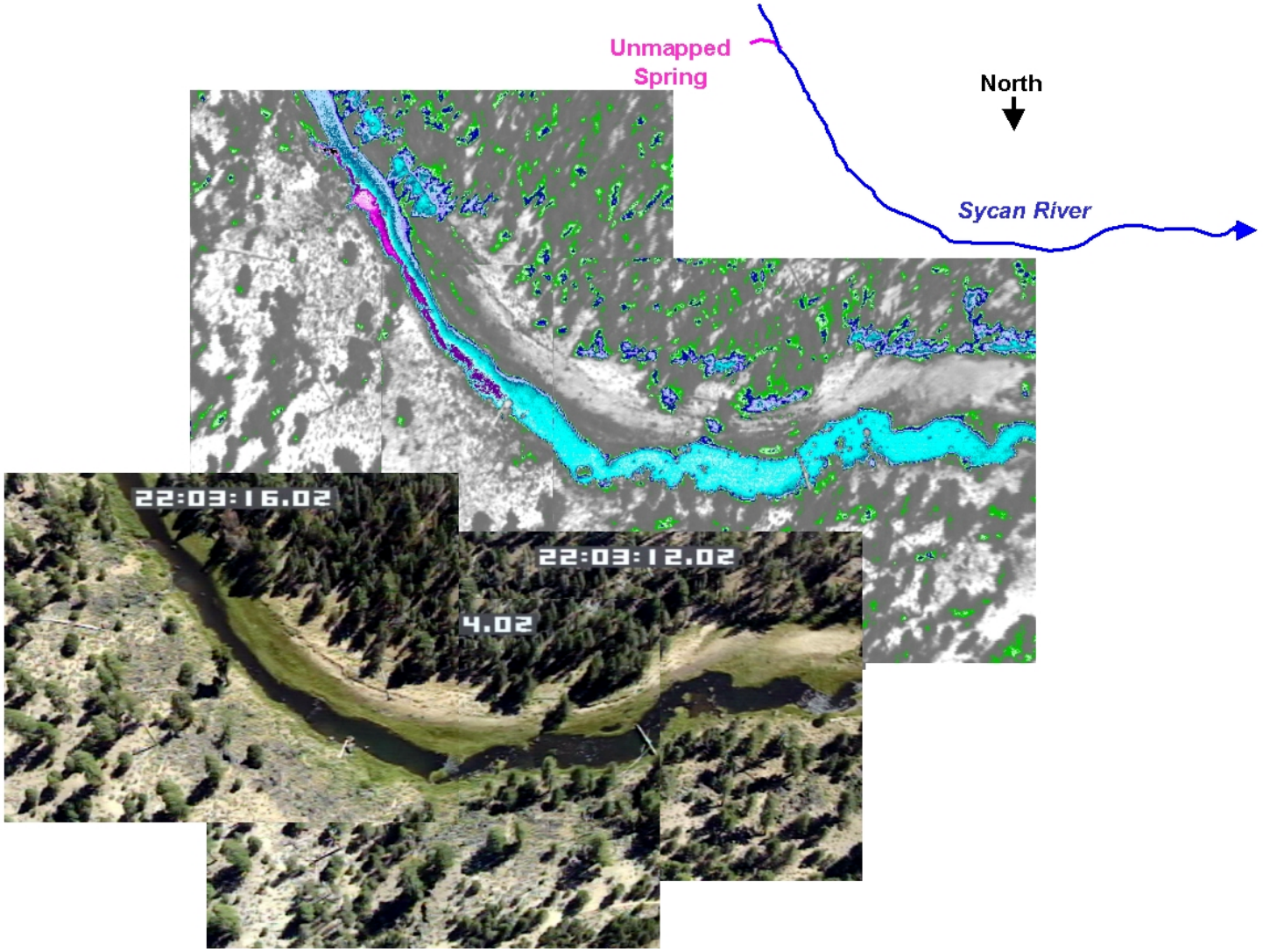
Sycan - Image 5. Sycan River – Microclimates – River Miles 64.52 to 64.64



FLIR Derived Temperature (°F) - August 16, 1999 (2:43 to 3:24 PM and 4:53 to 5:02 PM)



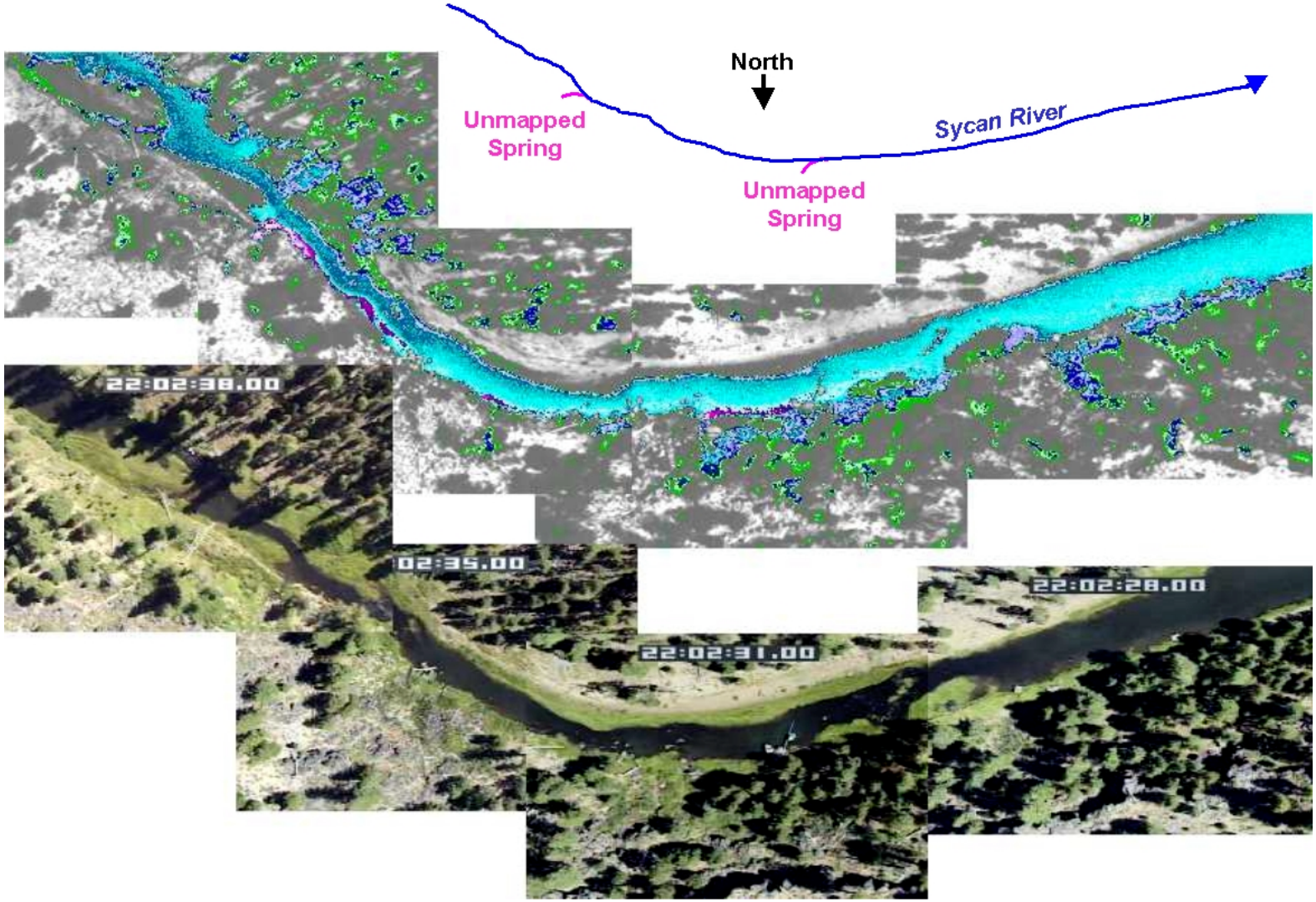
Sycan - Image 6. Sycan River – Unmapped Spring – River Miles 26.74 to 26.83



FLIR Derived Temperature (°F) - August 16, 1999 (2:43 to 3:24 PM and 4:53 to 5:02 PM)



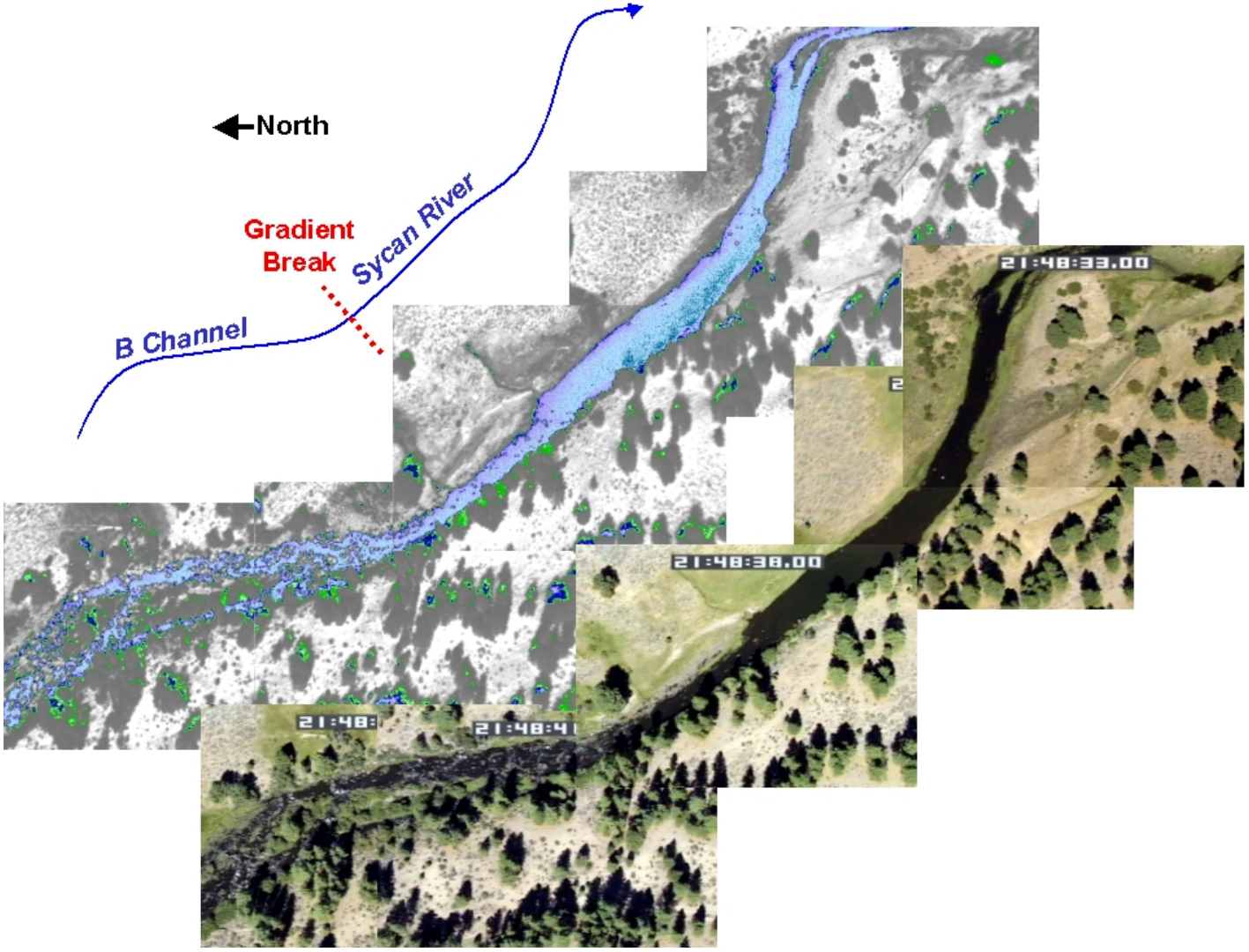
Sycan - Image 7. Sycan River – Unmapped Springs – River Miles 25.58 to 25.71



FLIR Derived Temperature (°F) - August 16, 1999 (2:43 to 3:24 PM and 4:53 to 5:02 PM)



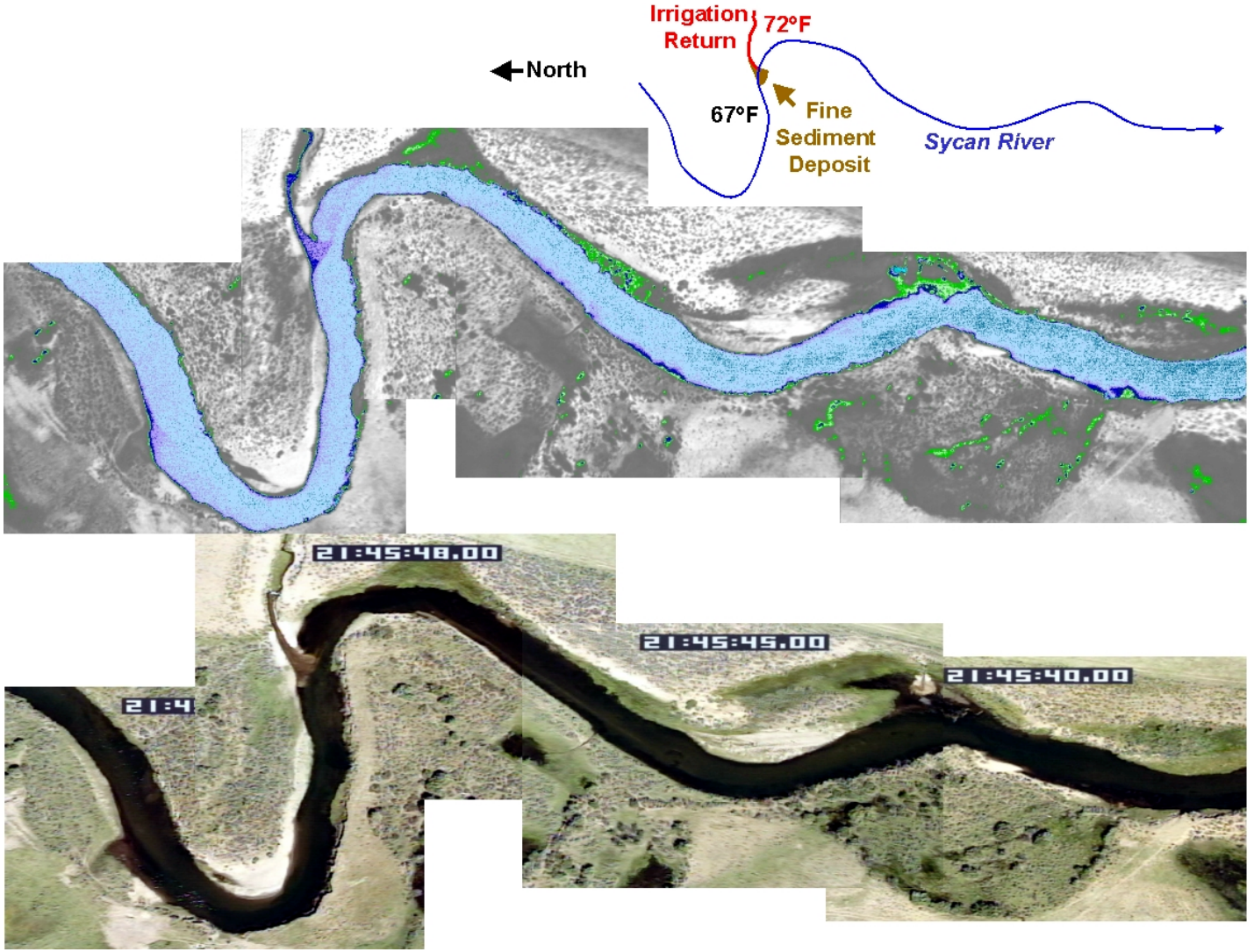
Sycan - Image 8. Sycan River –Gradient Drop – River Miles 9.18 to 9.50



FLIR Derived Temperature (°F) - August 16, 1999 (2:43 to 3:24 PM and 4:53 to 5:02 PM)

<50 | 50 | 52 | 54 | 55 | 57 | 59 | 61 | 63 | 64 | 66 | 68 | 70 | 72 | 73 | 75 | 81 | 83 | 85 →

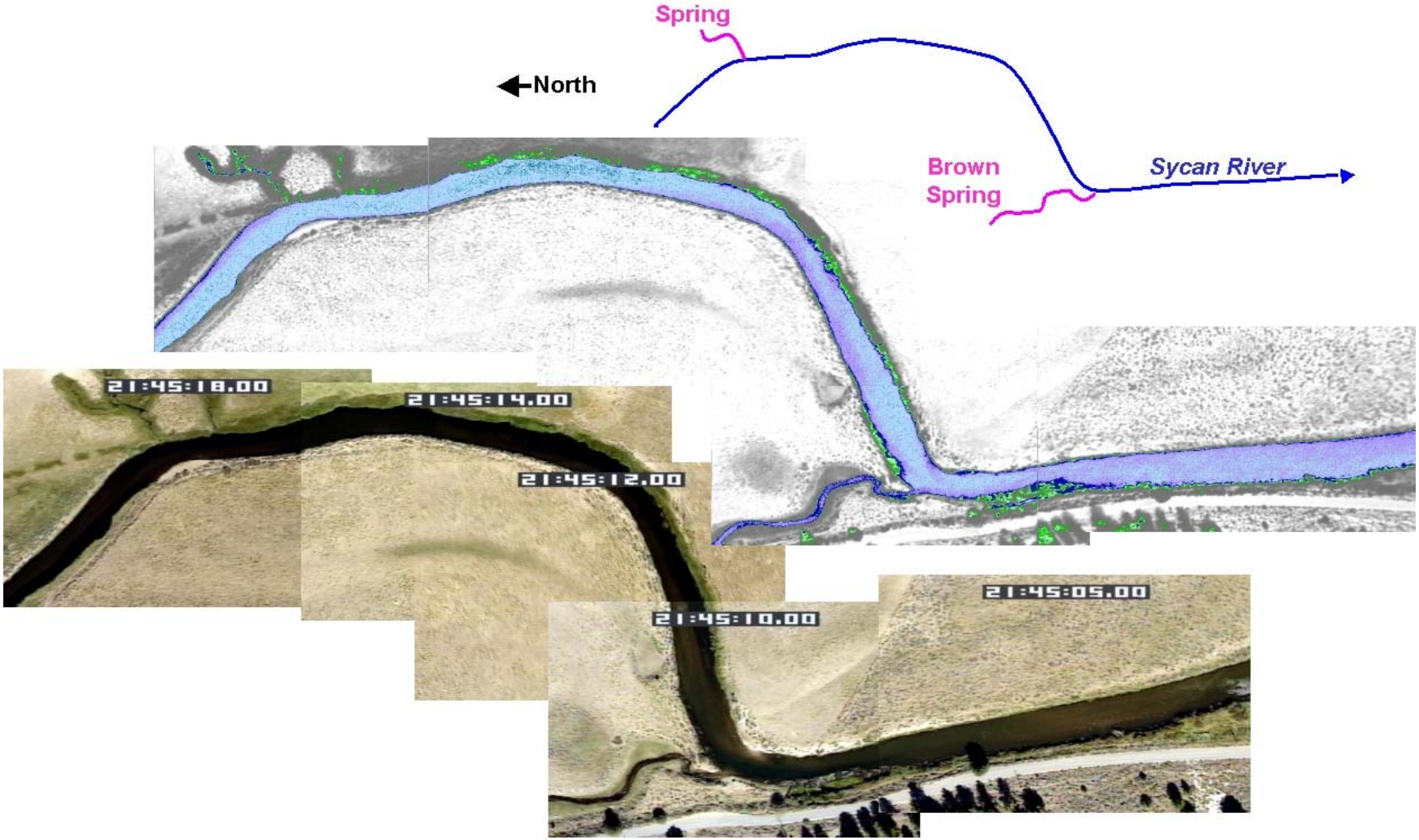
Sycan - Image 9. Sycan River – Irrigation Return – River Miles 4.73 to 5.04



FLIR Derived Temperature (°F) - August 16, 1999 (2:43 to 3:24 PM and 4:53 to 5:02 PM)



Sycan - Image 10. Sycan River – Brown Spring – River Miles 3.95 to 4.36



FLIR Derived Temperature (°F) - August 16, 1999 (2:43 to 3:24 PM and 4:53 to 5:02 PM)



2.5.2.3 Sprague River FLIR Derived Longitudinal Heating and Imagery

Sprague River longitudinal temperatures were sampled using FLIR on August 12, 1999 from 2:16 to 3:20 PM. **Figure 2-20** shows the FLIR flight path, color coded to display the measured stream temperature. At the time of FLIR sampling, the Sprague River temperatures ranged from about 68°F to the 73°F. **Figure 2-21** shows the FLIR derived stream temperature longitudinal profile.

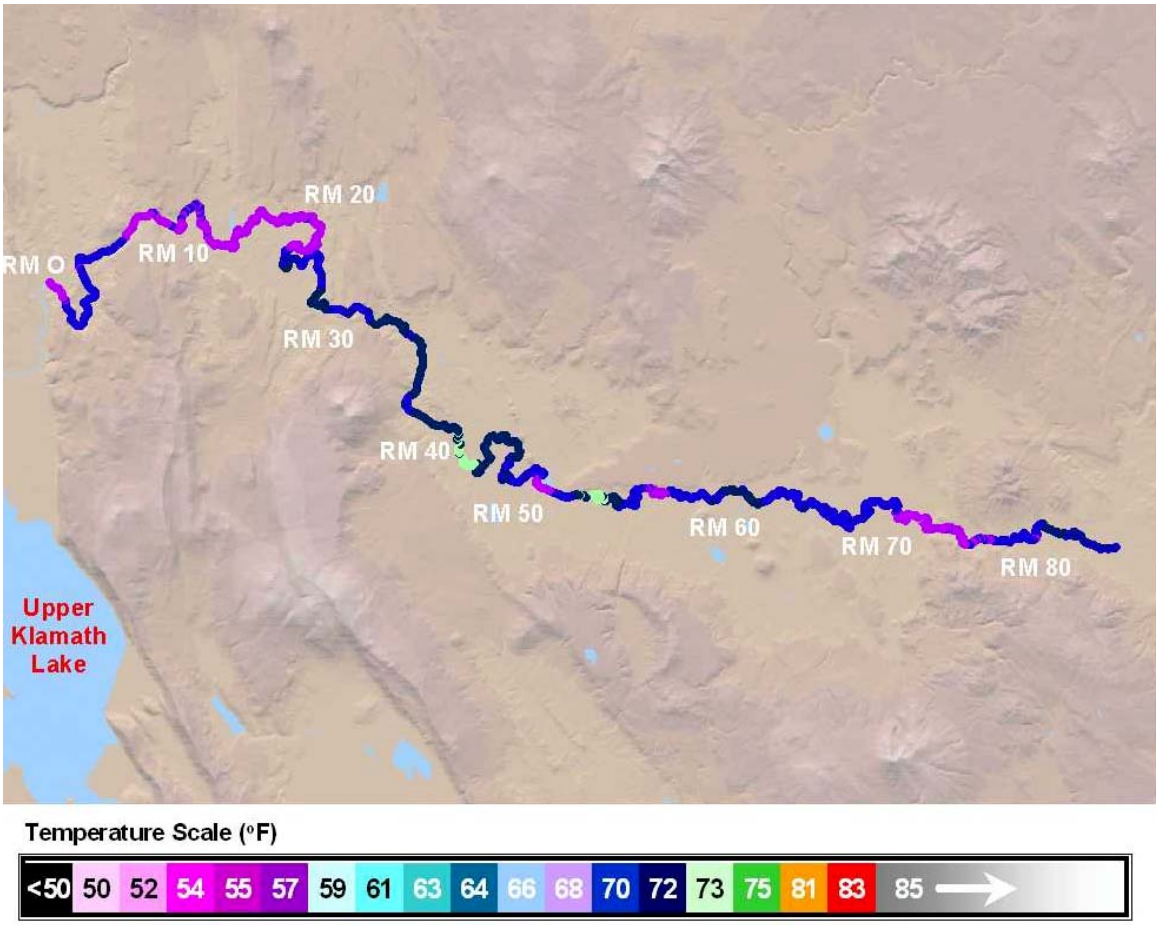


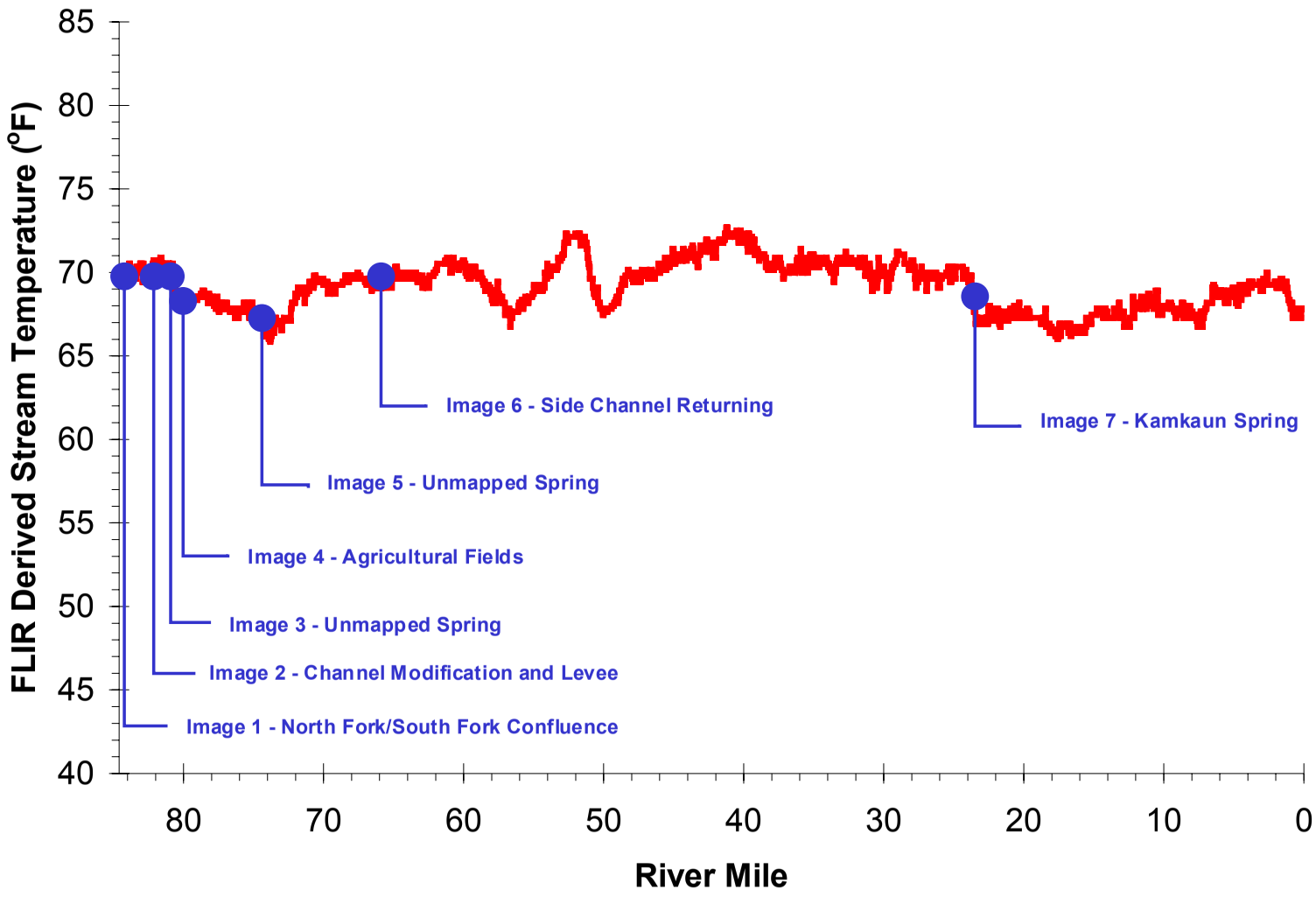
***Figure 2-20**. Sprague River Sampled FLIR Temperatures*

The temperature at the confluence of the North and South Forks (river mile 84.6) was approximately 70°F. Throughout the Sprague River mainstem there are many points of diversions and irrigation returns. As a result, the flow and thermal regime of the river fluctuates. In many river reaches there are diversion canals that re-direct large volumes of Sprague River water, sometimes rejoining the mainstem a mile or two downstream. Many Sprague River reaches have multiple channels, characteristic of a low-gradient meandering stream and fine substrates. Several springs enter the Sprague River and have varying degrees of cooling to the Sprague River temperature. For example, Kamkaun Spring (river mile 23.5) drops the mainstem temperature from 70°F to 66°F. Other stream segments have diffuse subsurface inflow that occur over a long distance (i.e. one mile). FLIR data reveal that the Sprague River is a naturally complex system that is highly modified by human land and water use. Stream temperature patterns are most affected by mass transfers to and from the river system.

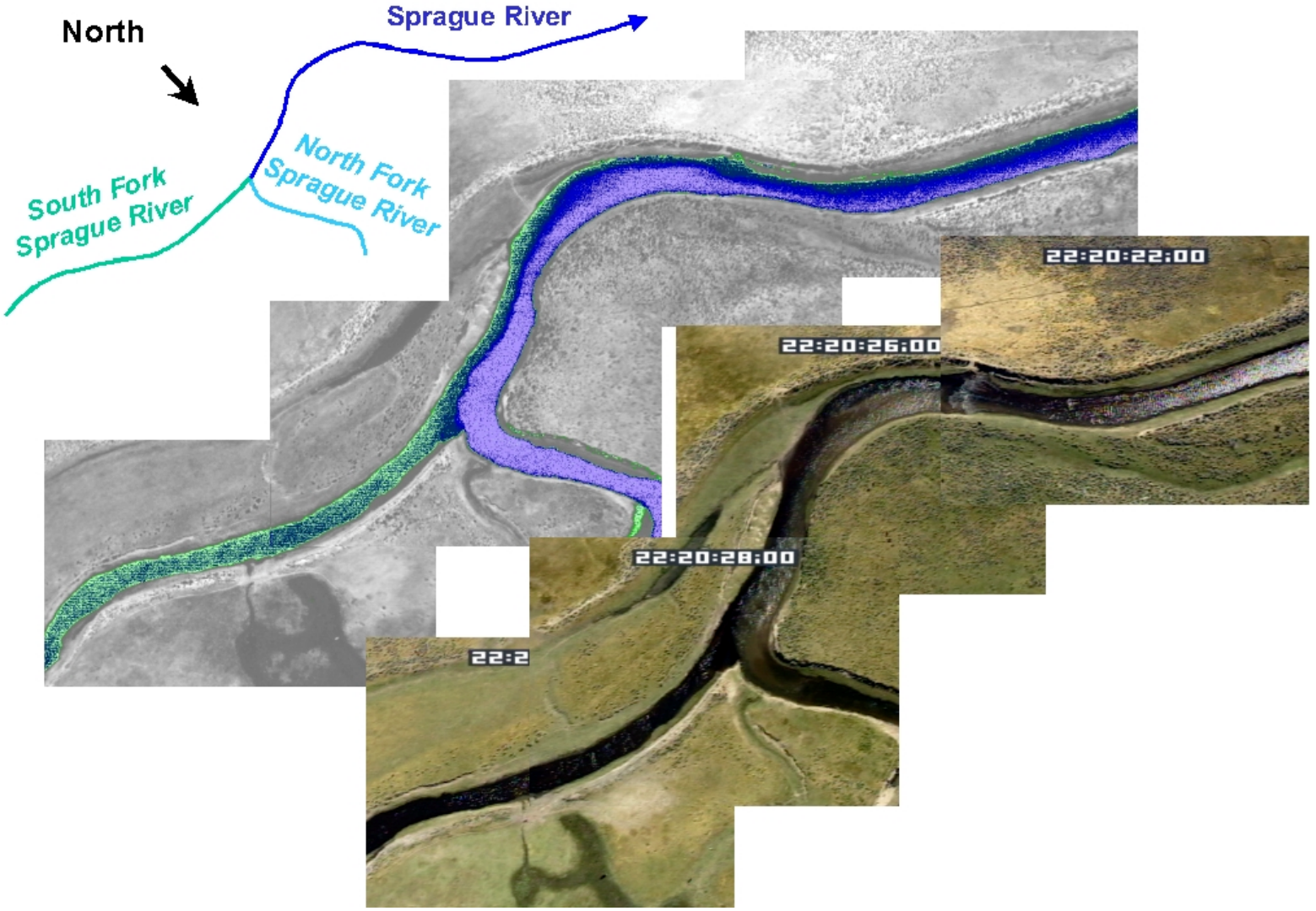
Summary of Selected FLIR Imagery - Sprague River

- **Sprague - Image A-1**. Sprague River – Confluence of North and South Forks - River Miles 84.45 to 84.60. The North Fork Sprague River is 64°F at its mouth, while the South Fork Sprague River is 72°F at its mouth. Complete mixing of the North and South Forks occurs over a short distance at the first downstream bend in the Sprague River.
- **Sprague - Image A-2.** Sprague River – Channel Modification and Levee – River Miles 82.43 to 81.88. These images display a 1.45-mile reach where the Sprague River has undergone extensive channel modifications and a canal that diverts much of the stream along a levee.
- **Sprague - Image A-3**. Sprague River – Unmapped Spring – River Miles 80.74 to 81.18. A 59°F spring cools the mainstem temperature from approximately 70°F to 68°F.
- **Sprague - Image A-4**. Sprague River – Agricultural Fields - River Miles 79.46 to 80.23. The near stream area is bordered by cultivated fields and remnants of woody and shrub land cover. The surface area of the cultivated fields exceeds 85°F, while the remnant areas of woody land cover (likely to be willows) is in the lower 70°F range.
- **Sprague - Image A-5.** Sprague River – Unmapped Spring - River Miles 74.26 to 74.66. This unmapped spring cools the mainstem temperature about 2°F.
- **Sprague - Image A-6.** Sprague River – Side Channel Returning - River Miles 65.57 to 66.18. At the lower left corner of the imagery is a side channel returning to the Sprague River, 1.7 miles after branching off of the mainstem. The returning water is significantly warmer than the mainstem and a warm plume can be observed along the right bank.
- **Sprague - Image A-7.** Sprague River – Kamkaun Spring - River Miles 23.29 to 23.82. Kamakaun Spring is cooling the mainstem temperature from about 70°F to 66°F. The spring appears to have a significant flow contribution of 55°F water.

Figure 2-21. Sprague River FLIR Derived Temperatures - August 12, 1999 – 2:16 to 3:20 PM



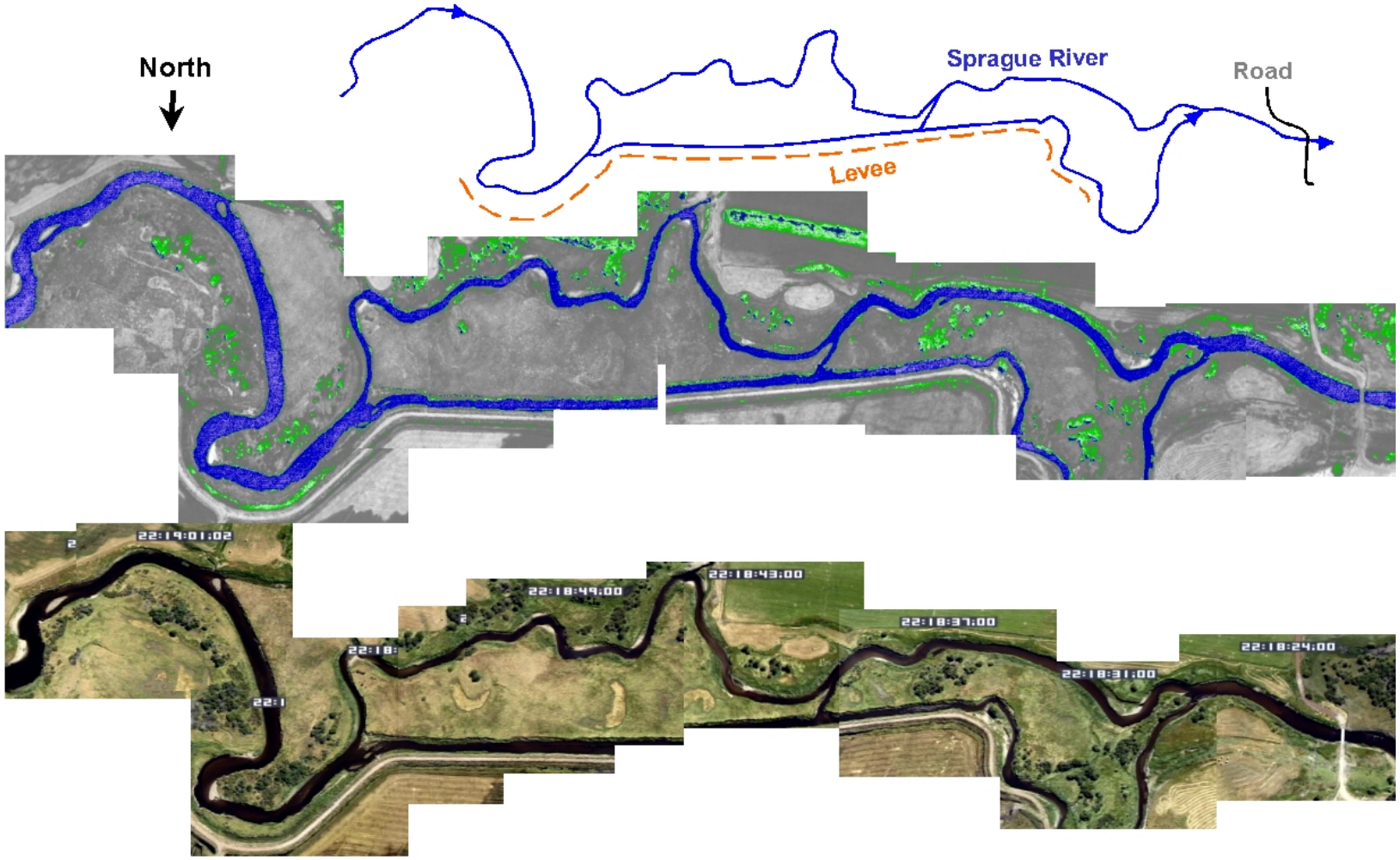
Sprague - Image A-1. Sprague River – Confluence of North and South Forks - River Miles 84.45 to 84.60



FLIR Derived Temperature (°F) - August 12, 1999 (2:16 to 3:20 PM)



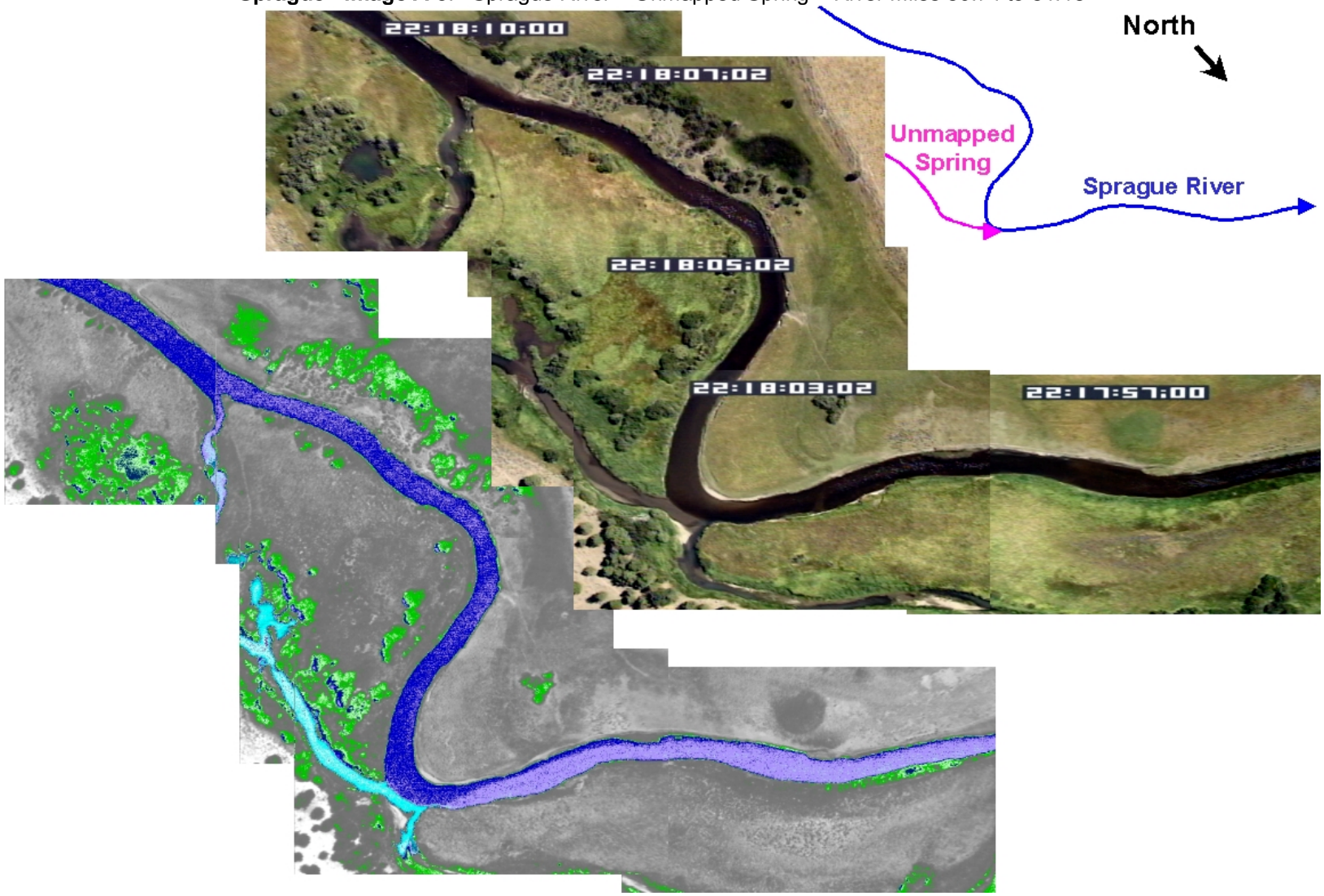
Sprague - Image A-2. Sprague River – Channel Modification and Levee – River Miles 81.43 to 82.88



FLIR Derived Temperature (°F) - August 12, 1999 (2:16 to 3:20 PM)

<50 | 50 | 52 | 54 | 55 | 57 | 59 | 61 | 63 | 64 | 66 | 68 | 70 | 72 | 73 | 75 | 81 | 83 | 85

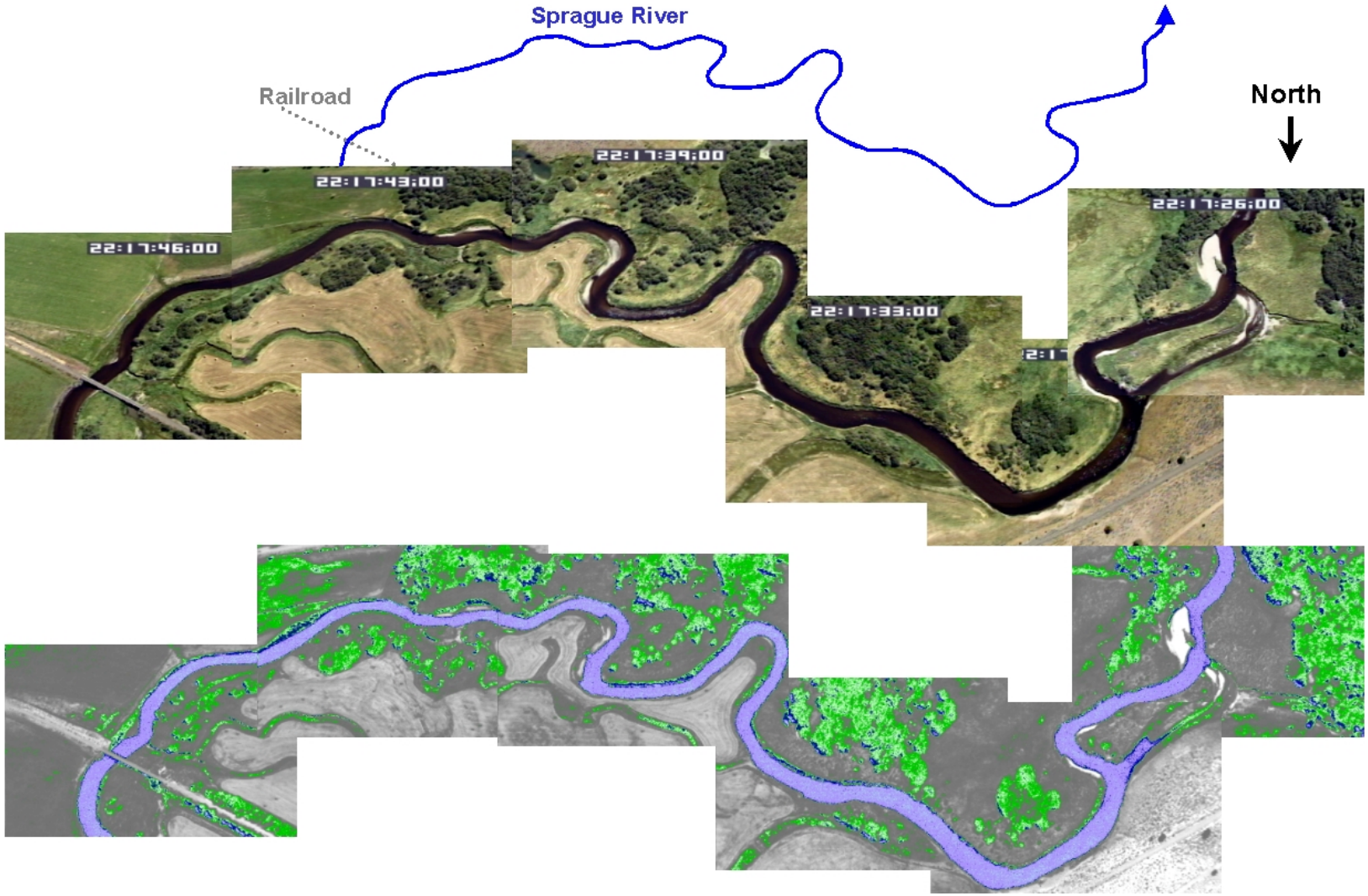
Sprague - Image A-3. Sprague River – Unmapped Spring – River Miles 80.74 to 81.18



FLIR Derived Temperature (°F) - August 12, 1999 (2:16 to 3:20 PM)



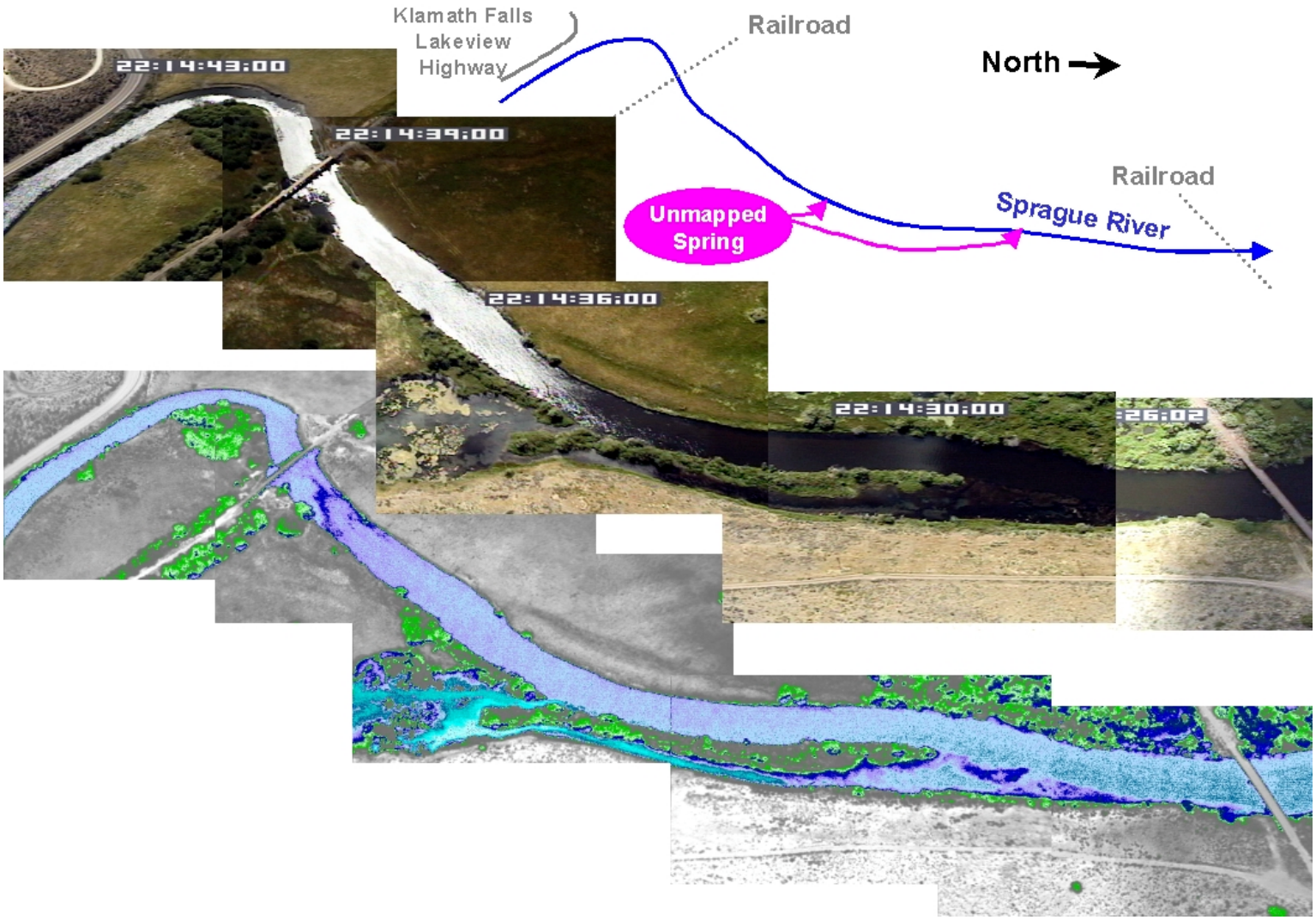
Sprague - Image A-4. Sprague River – Agricultural Fields - River Miles 79.46 to 80.23



FLIR Derived Temperature (°F) - August 12, 1999 (2:16 to 3:20 PM)



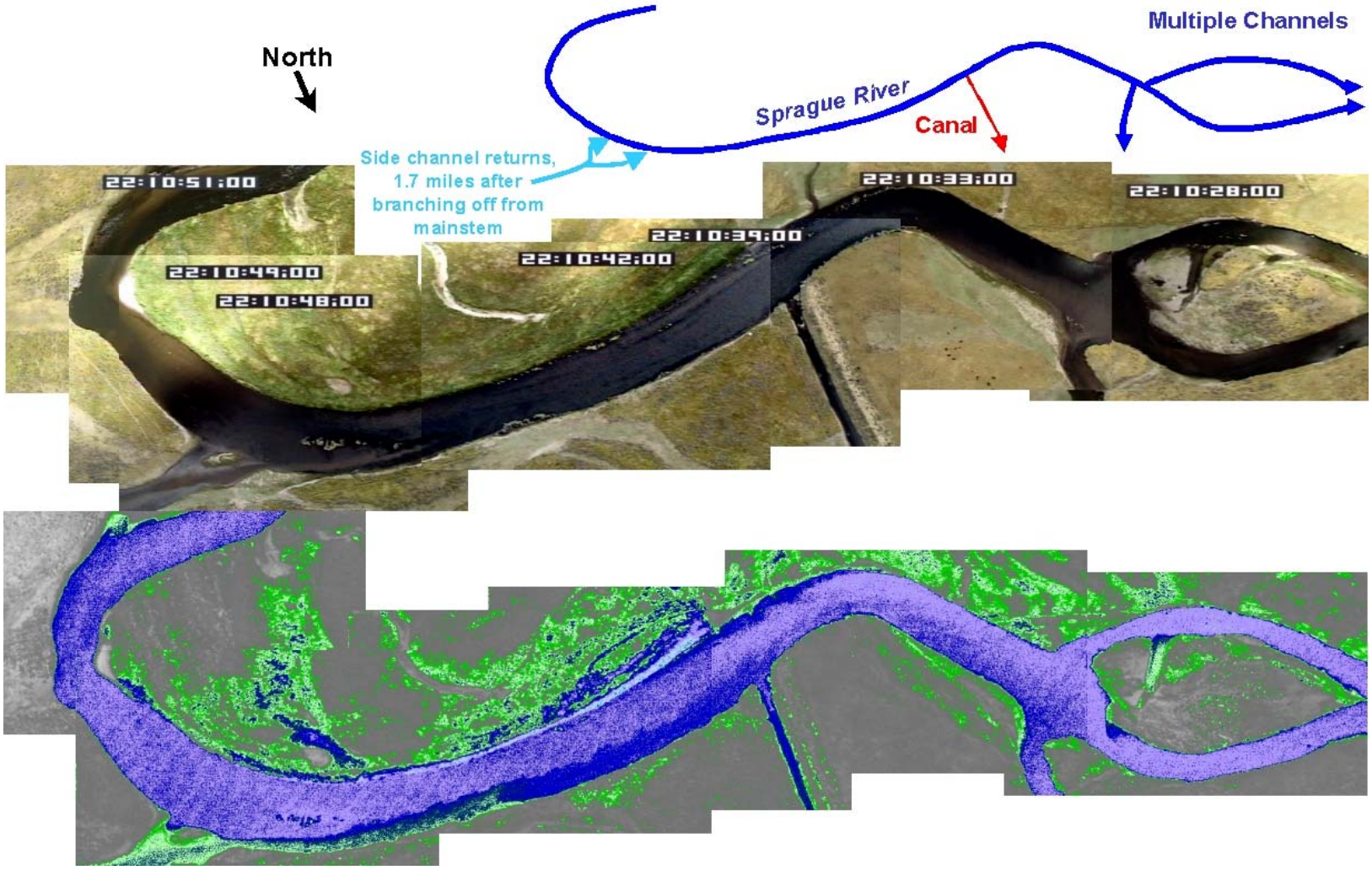
Sprague - Image A-5. Sprague River – Unmapped Spring - River Miles 74.26 to 74.66



FLIR Derived Temperature (°F) - August 12, 1999 (2:16 to 3:20 PM)



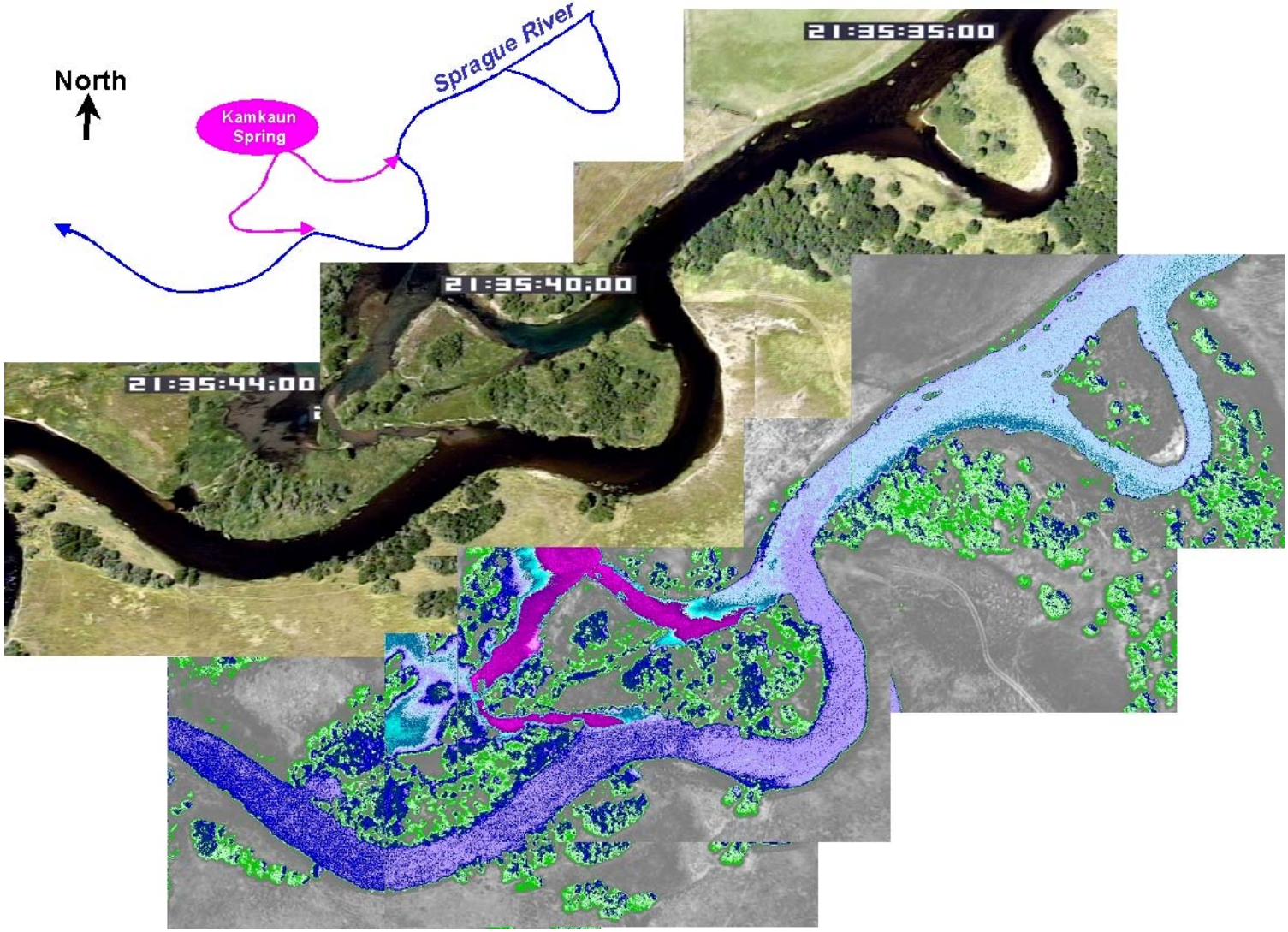
Sprague - Image A-6. Sprague River – Side Channel Returning - River Miles 65.57 to 66.18



FLIR Derived Temperature (°F) - August 12, 1999 (2:16 to 3:20 PM)

<50 | 50 | 52 | 54 | 55 | 57 | 59 | 61 | 63 | 64 | 66 | 68 | 70 | 72 | 73 | 75 | 81 | 83 | 85

Sprague - Image A-7. Sprague River – Kamkaun Spring - River Miles 23.29 to 23.82



FLIR Derived Temperature (°F) - August 12, 1999 (2:16 to 3:20 PM)



2.2.5.4 North Fork Sprague River FLIR Derived Longitudinal Temperature and Imagery

North Fork Sprague River longitudinal temperatures were sampled using FLIR on August 16, 1999 between 4:20 PM and 4:40 PM. Temperature data sampled from FLIR imagery reveals a spatial pattern that is variable due to localized high rates of stream heating, numerous flow withdrawals, large contributions of subsurface flow and tributary mixing. For discussion purposes, the North Fork Sprague is broken into an upper section (river miles 23 to 34), middle section (river miles 12 to 23) and lower section (river miles 0 to 12). **Figure 2-22** graphically displays FLIR-sampled temperatures for the North Fork Sprague River. The longitudinal temperature profile for the North Fork Sprague River is presented in **Figure 2-25**.

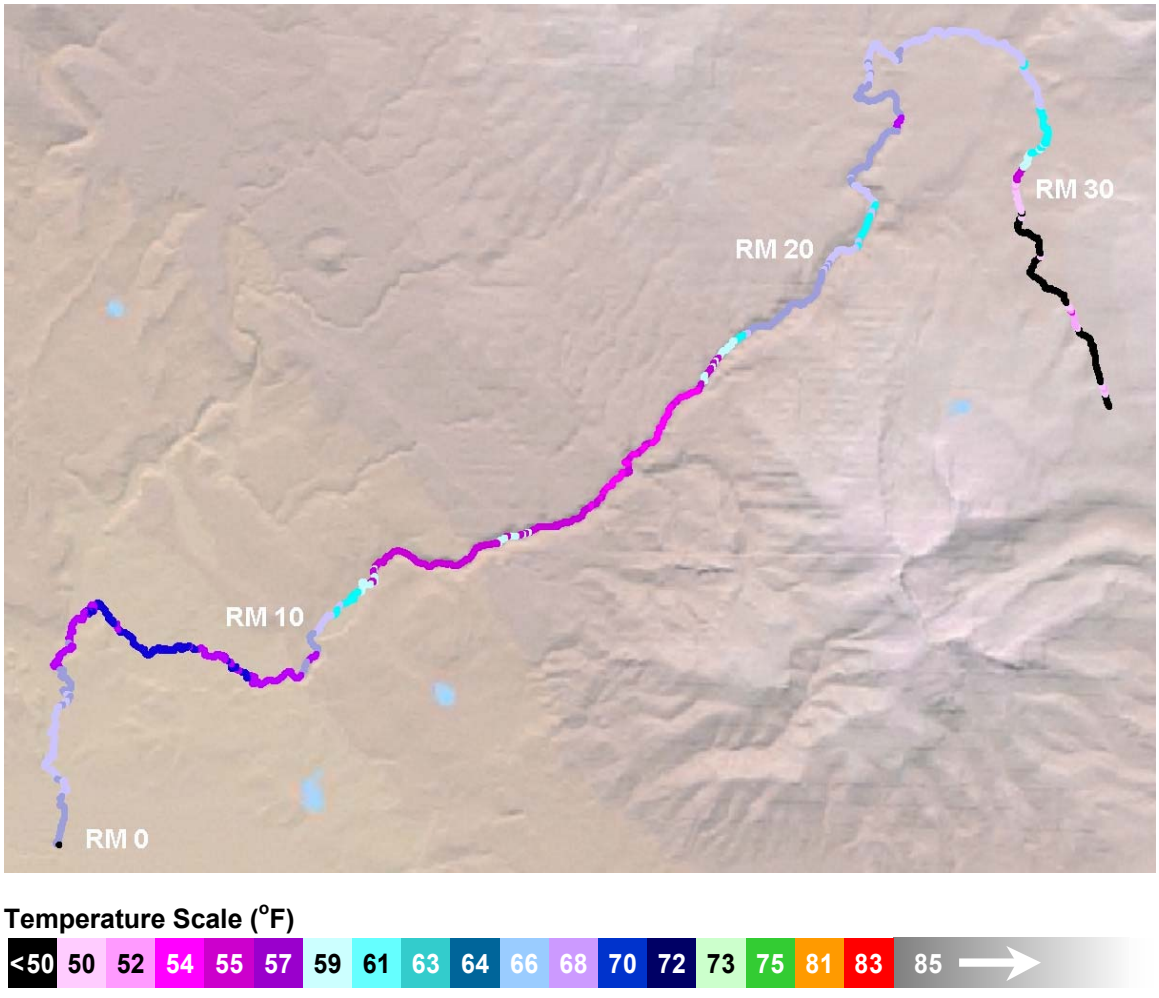
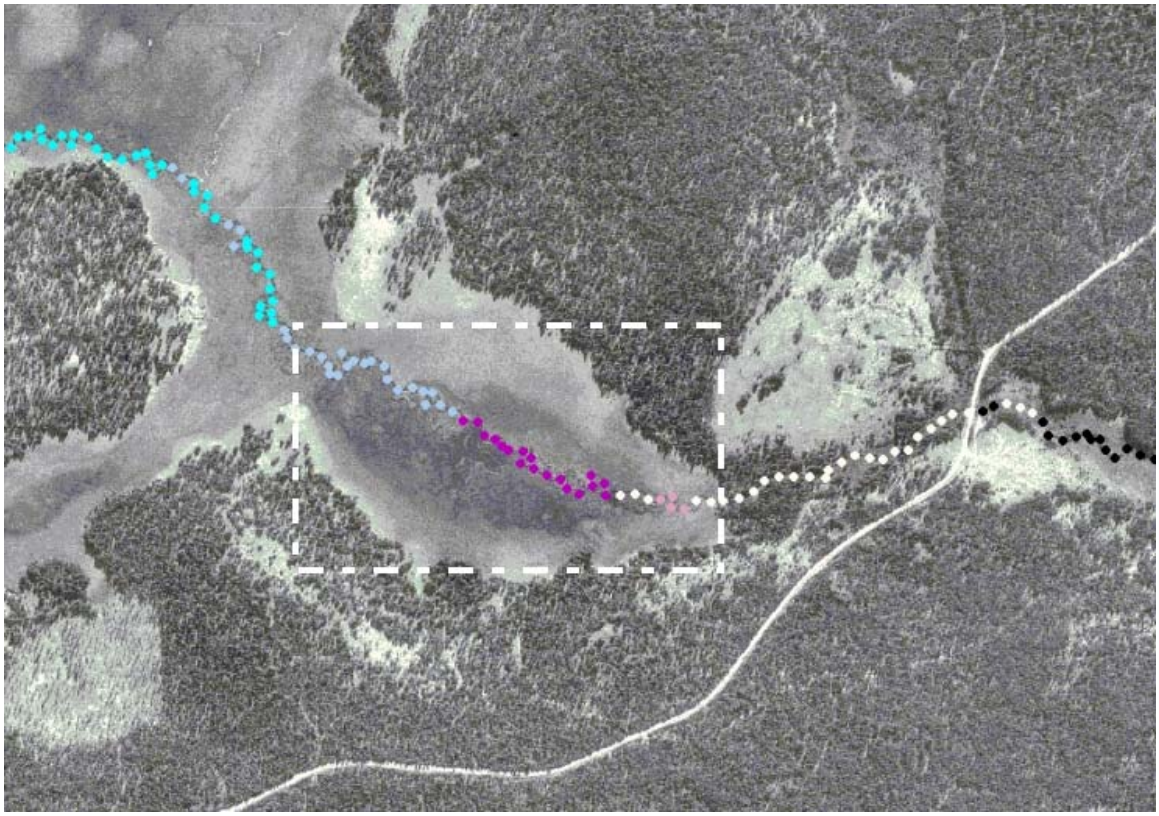


Figure 2-22. *North Fork Sprague River Sampled FLIR Temperatures* - August 16, 1999 – (4:20 PM to 4:44 PM)

Upper North Fork Sprague River Heating Gradients - RM 23-34

FLIR sampled temperatures in the upper North Fork Sprague River show variable spatial distributions (45°F to 65°F). Cool areas are associated with springs/groundwater inflow. The upper North Fork Sprague River originates from a series of springs, with 55°F stream temperatures above Lee Thomas Meadow. Stream temperatures increase dramatically as the North Fork Sprague River travels through Lee Thomas Meadow, with a heating gradient of 9°F per mile (**Figure 2-23**). The stream temperature increases rapidly at the upper end of Lee Thomas Meadow, and those high temperatures are maintained throughout downstream distance of the meadow.



Temperature Scale (°F)



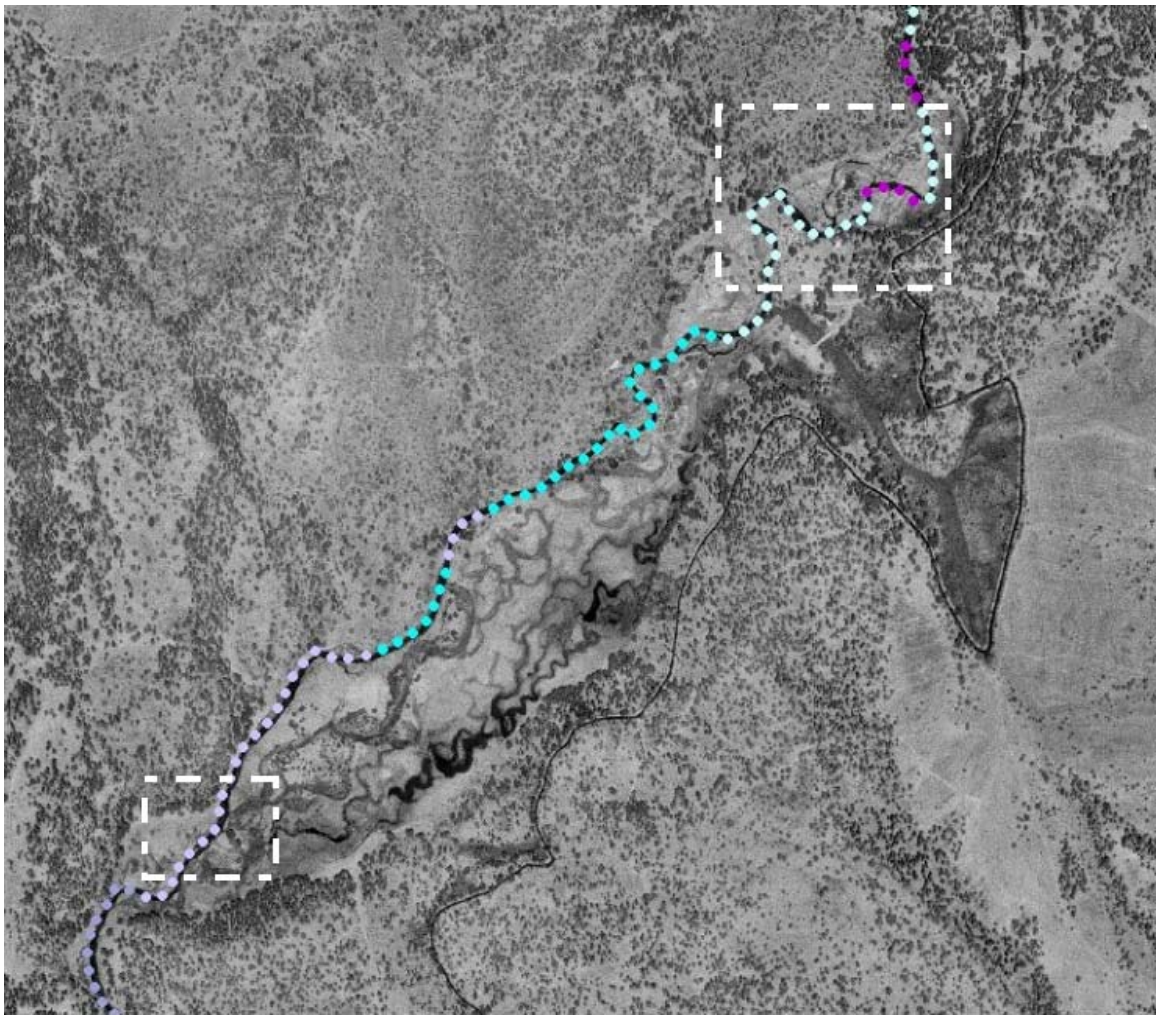
***Figure 2-23**. Temperature Profile in Upper Lee Thomas Meadow (Dashed Box indicate the area highlighted in North Fork Sprague - Image 1.)* - August 16, 1999 – (4:20 PM to 4:44 PM)

Middle North Fork Sprague River Heating Gradients - RM 12-23

Temperatures become highly variable as the river travels out of Lee Thomas Meadow back into a forested area. Several major springs cool the mainstem within this reach and add flow volume.

Water temperatures decrease downstream of a several springs around river mile 22. However, stream temperatures quickly heat in the two-mile reach downstream from these springs.

Several major springs and cold tributaries were observed between river miles 15 and 20. Temperature decreases rapidly within this reach, and are maintained at low levels of heating. The stream heating longitudinal gradients within this reach was 0.3°F per mile.



Temperature Scale (°F)

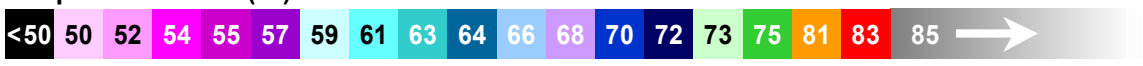


***Figure 2-24**. Temperature profile in Bailey Flat (Dashed Boxes indicate areas highlighted in North Fork Sprague - Images 6 and 7.)* - August 16, 1999 – (4:20 PM to 4:44 PM)

Lower North Fork Sprague River Heating Gradients - RM 0-12

Sampled temperatures in the lower North Fork Sprague River had a variable spatial distribution, with temperatures increasing rapidly as the river traveled out of forested areas and into the lower meadow system at Bailey Flat where the stream heating gradient within was 3.5°F per mile. Bailey Flat is illustrated in **Figure 2-24**. This high rate of heating is the result of low levels of stream shade, flow withdrawals, the return of diverted water, and channel modifications. Elevated stream temperatures are maintained for three to four miles downstream from Bailey Flat. Water temperatures decrease slightly as the river travels downstream into the Sprague River Valley. Water temperatures increase once again near the mouth of the North Fork Sprague following a major water diversion at River Mile 2.3.

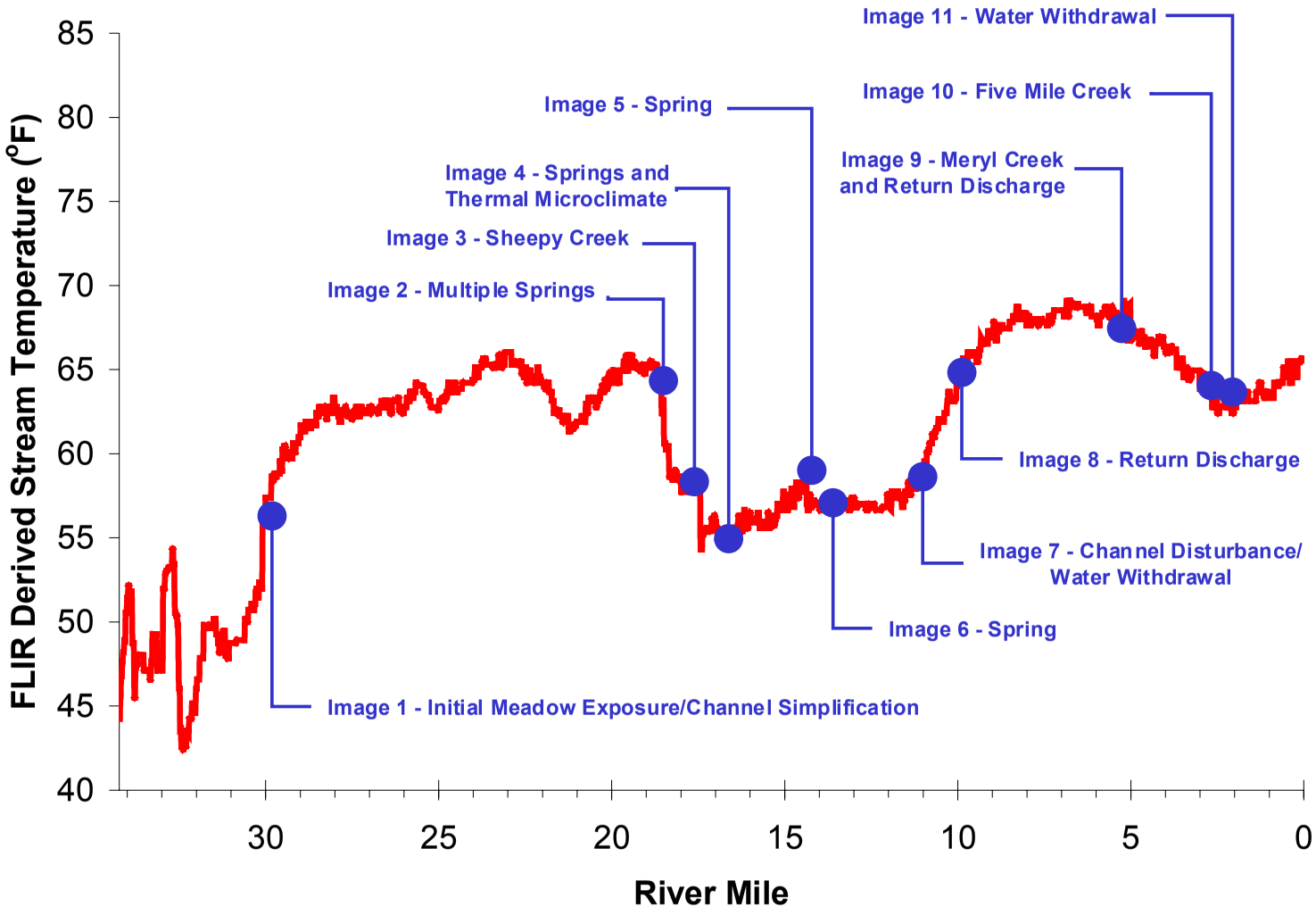
Summary of Selected FLIR Imagery - North Fork Sprague

- **North Fork Sprague - Image 1**. North Fork Sprague River – Meadow Disturbance/Channel Simplification - River Miles 29.59 to 30.24. The initial solar exposure (due to low levels of stream shade) of the North Fork Sprague River in Lee Thomas Meadow allows stream temperature increases rapidly. This area is a primary zone of stream heating in the North Fork Sprague River.
- **North Fork Sprague - Image 2**. North Fork Sprague River – Area with Multiple Springs - River Miles 18.41 to 18.65. The discharge of multiple springs cools stream temperatures in the North Fork Sprague River.
- **North Fork Sprague - Image 3**. North Fork Sprague River and Sheepy Creek Confluence - River Miles 17.46 to 17.55. A cold water tributary on mainstem temperatures in the North Fork Sprague River cools downstream temperature to below 55°F.
- **North Fork Sprague - Image 4**. North Fork Sprague River – Thermal Microclimate - River Miles 16.54 to 16.99. Recent harvest activities are evident on the left stream bank by warmer surface temperatures. Alternatively, the intact forest stands on the right bank have cooler surface temperatures. Such differential heating is an indication of thermal microclimate temperature increases that accompany the removal of stand structure.
- **North Fork Sprague - Image 5**. North Fork Sprague River – Spring Influence - River Miles 14.41 to 14.47. The spring illustrated in this image is a typical spring within this reach of the river.
- **North Fork Sprague - Image 6**. North Fork Sprague River - Spring Influence - River Miles 13.89 to 14.03. The effect of spring flow on water temperature can be seen in this image.
- **North Fork Sprague - Image 7**. North Fork Sprague River – Channel Disturbance and Water Withdrawal - River Miles 10.70 to 11.36. Stream temperatures warm as the North Fork Sprague River travels into Bailey Flat. A 3.5°F per mile stream heating longitudinal gradient is observed within Bailey Flat. This high rate of heating is the result of low levels of stream shade, flow withdrawals, the return of diverted water, and channel modifications.
- **North Fork Sprague - Image 8**. North Fork Sprague River – Warm Return Flow - River Miles 9.99 to 10.16. This image shows the temperature response resulting from the return of diverted water back into the North Fork Sprague River located at the lower end of Bailey Flat (1.2 miles downstream of **Image 7**). Water temperatures increase in response to the warm water mass transfer. The return water illustrated in this image was withdrawn for the North Fork Sprague at the top of this Bailey Flat. Water temperatures increases within this reach are likely exacerbated through other heat transfer processes in addition to mass transfer

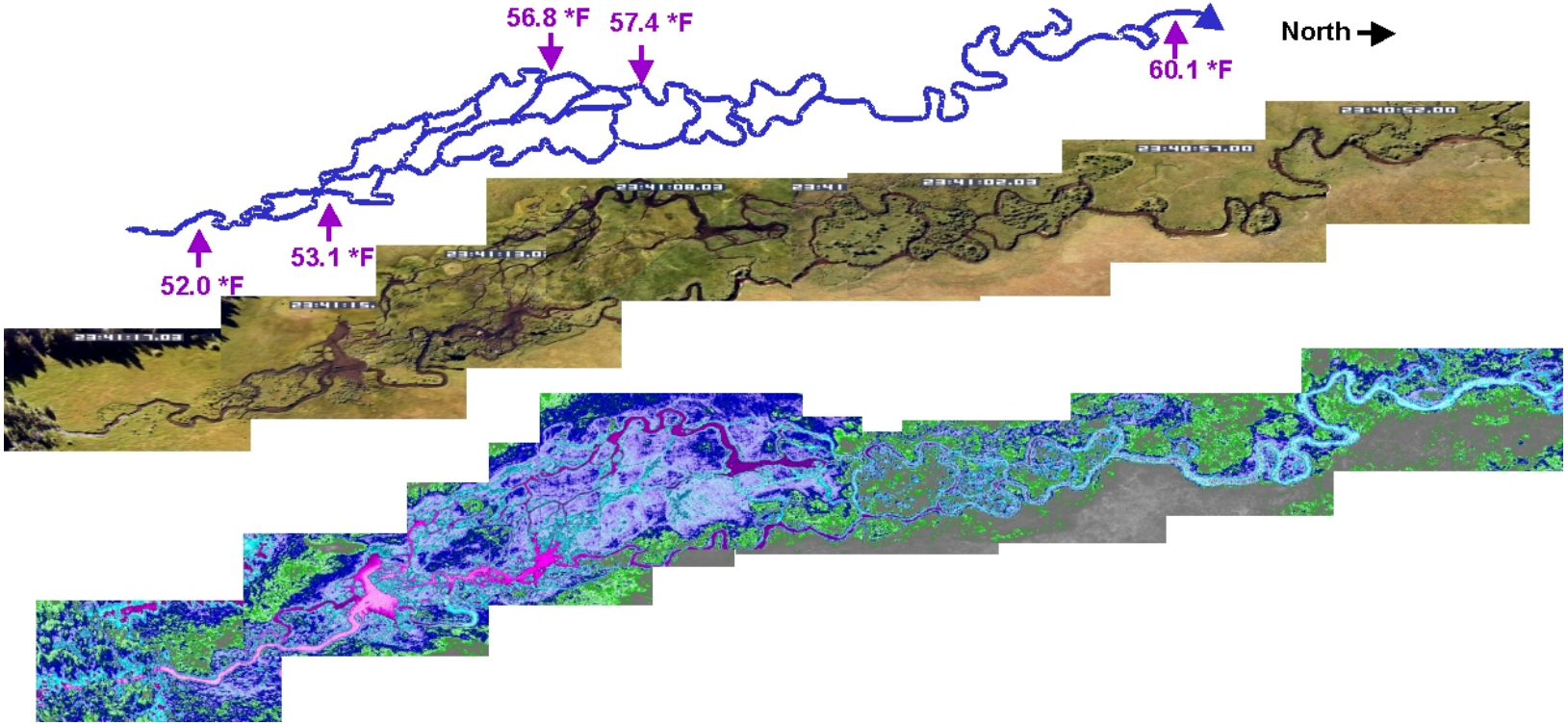
warming (i.e. decreased instream flow, low levels of shade and channel modifications also contribute to high rates of stream warming).

- **North Fork Sprague - Image 9**. North Fork Sprague River – Return Flow and Meryl Creek Confluence - River Miles 5.04 to 5.51. This image shows the complex nature on multiple mass transfer processes. Both a warm water return flow and the Meryl Creek confluence affect instream temperatures. Returns from an upstream withdrawal contribute a small volume of 72^{o}F water. Meryl Creek is 63^{o}F at the confluence and contributes a large volume of water, with a combined effect of 1.3^{o}F cooling to the North Fork Sprague River.
- **North Fork Sprague - Image 10**. North Fork Sprague River - Five Mile Creek Confluence - River Miles 2.61 to 2.72. The temperature of Five Mile Creek is slightly cooler than the North Fork Sprague River. River hydraulics within this stretch of the river are modified (i.e., reduced velocities, increased depths) by a diversion pushup dam located 0.3 miles downstream of this image. Riparian vegetation is mostly absent. A small water temperature decrease was observed downstream of this confluence.
- **North Fork Sprague - Image 11**. North Fork Sprague River – Water withdrawals and return flows - River Miles 2.30 to 2.38. This image shows a diversion push up dam. Several agriculture warm water return flows are entering the river downstream of this dam. Water temperatures increase downstream of this diversion, like due to the combined effect of decreases flow volume and warm water mass transfers associated with the agriculture return flows.

Figure 2-25. North Fork Sprague River FLIR Derived Temperatures - August 16, 1999 – (4:20 PM to 4:44 PM)



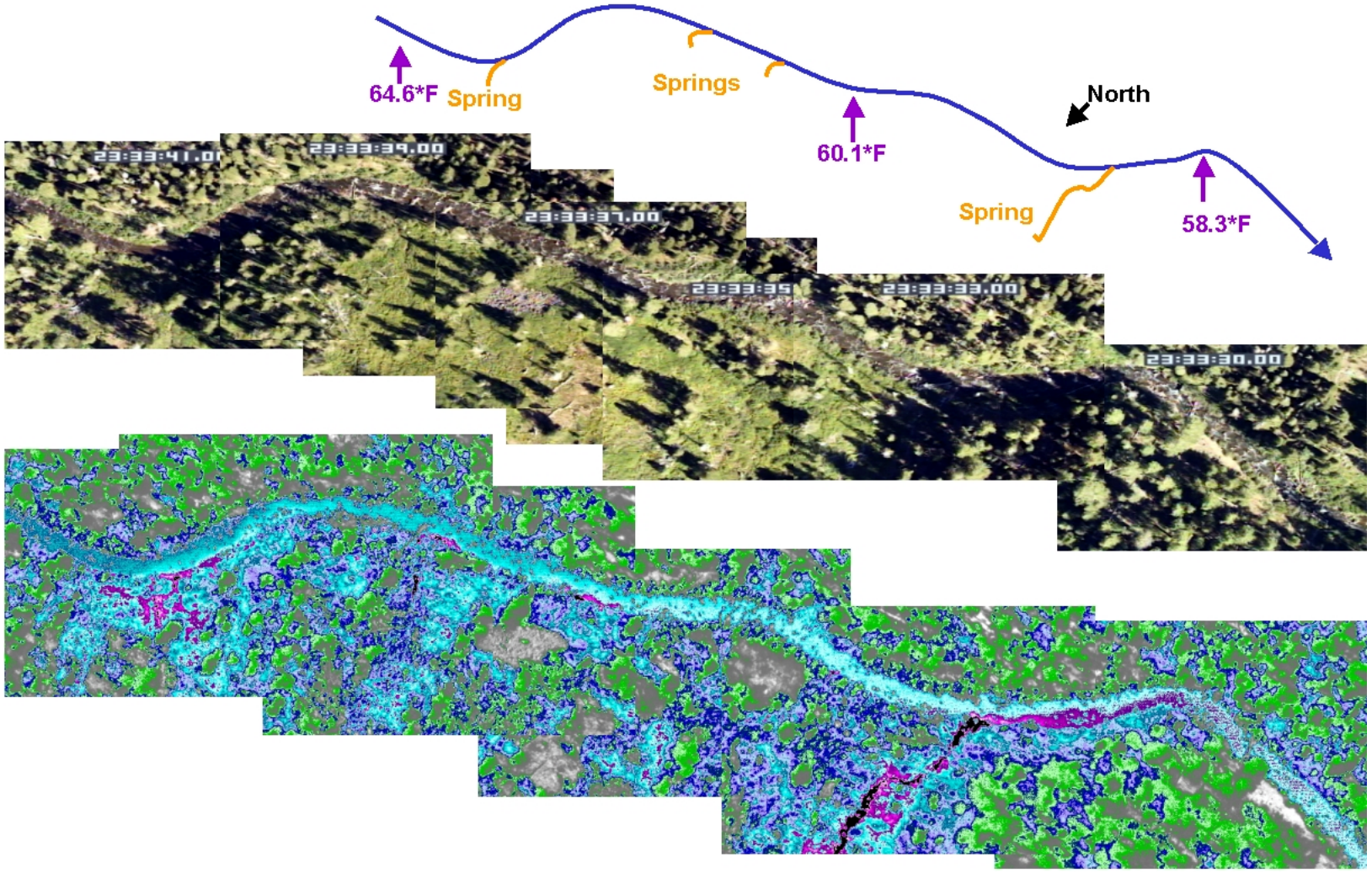
North Fork Sprague - Image 1. – North Fork Sprague River – Meadow Disturbance/Channel Simplification - River Miles 29.59 – 30.24.



FLIR Derived Temperature (°F) - August 16, 1999 (4:20 PM to 4:44 PM)



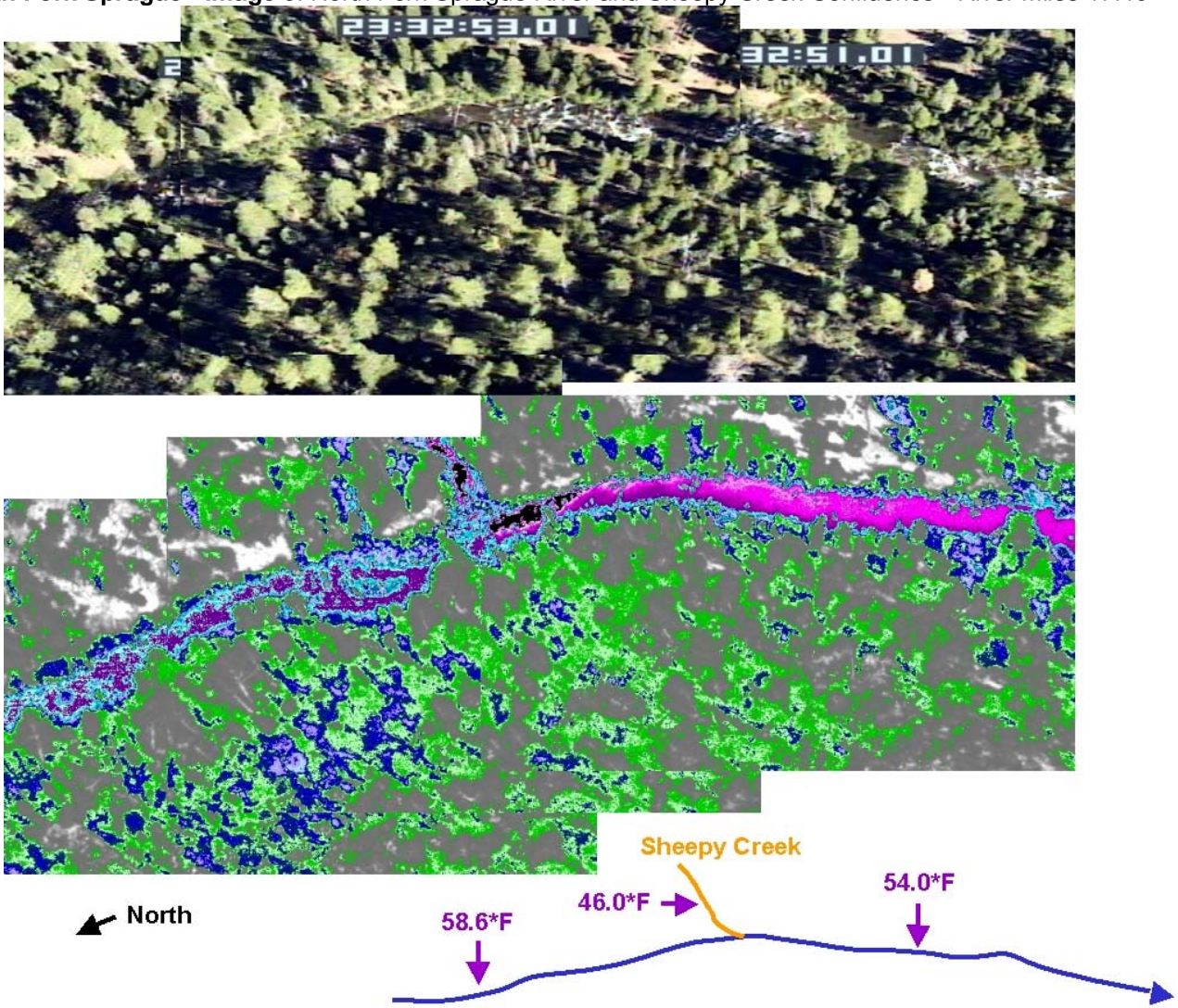
North Fork Sprague - Image 2. North Fork Sprague River – Area with Multiple Springs - River Miles 18.41 - 18.65



FLIR Derived Temperature (°F) - August 16, 1999 (4:20 PM to 4:44 PM)



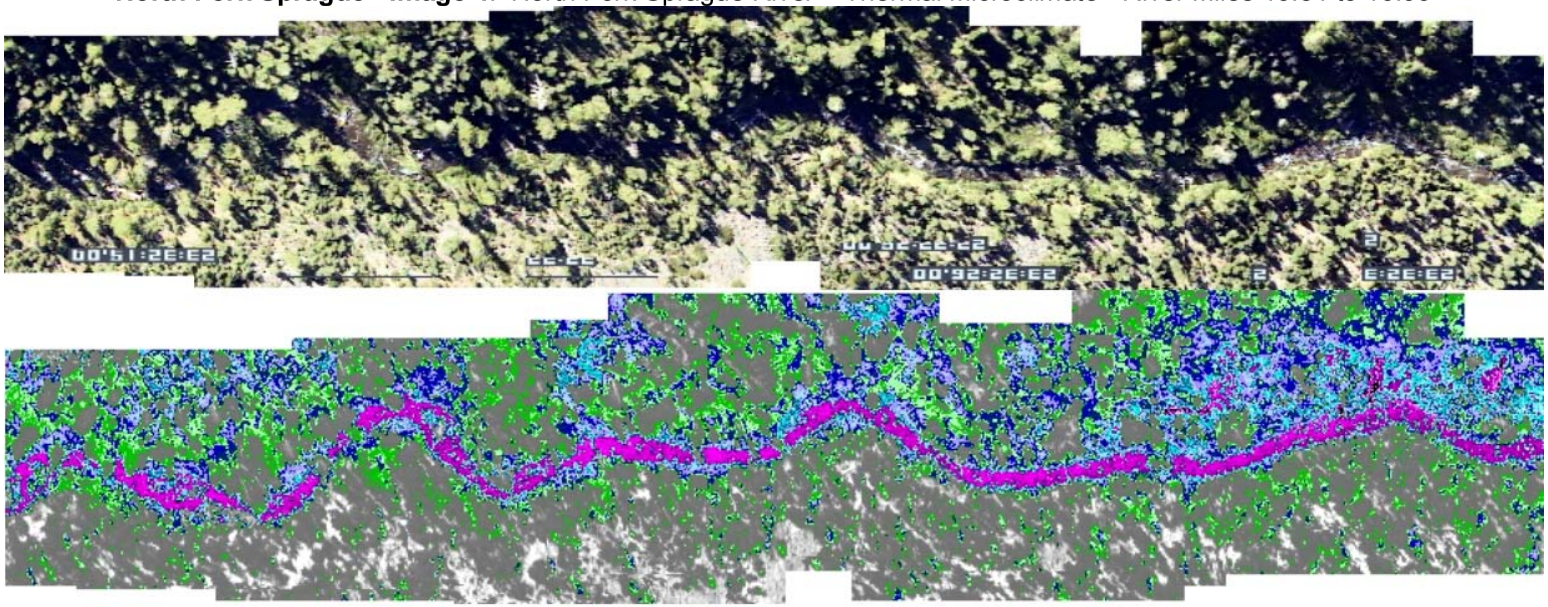
North Fork Sprague - Image 3. North Fork Sprague River and Sheepy Creek Confluence - River Miles 17.46 – 17.55

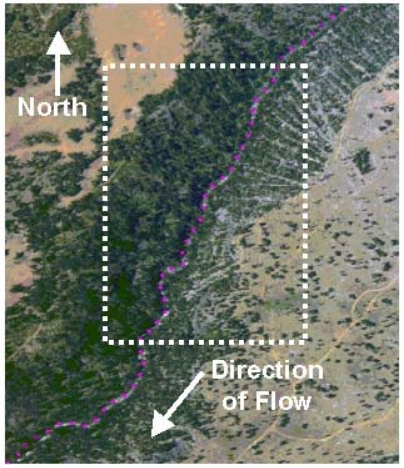


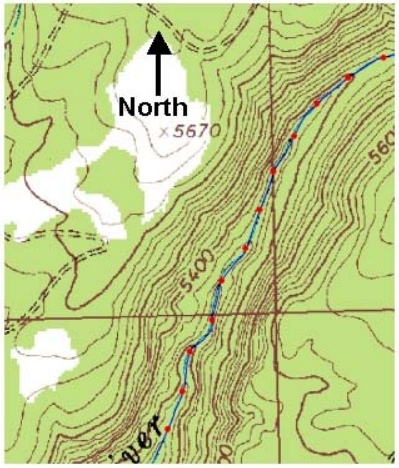
FLIR Derived Temperature (°F) - August 16, 1999 (4:20 PM to 4:44 PM)



North Fork Sprague - Image 4. North Fork Sprague River – Thermal Microclimate - River Miles 16.54 to 16.99







North

No Timber Harvest
Lower Surface Temperatures Indicate
Cooler Microclimate

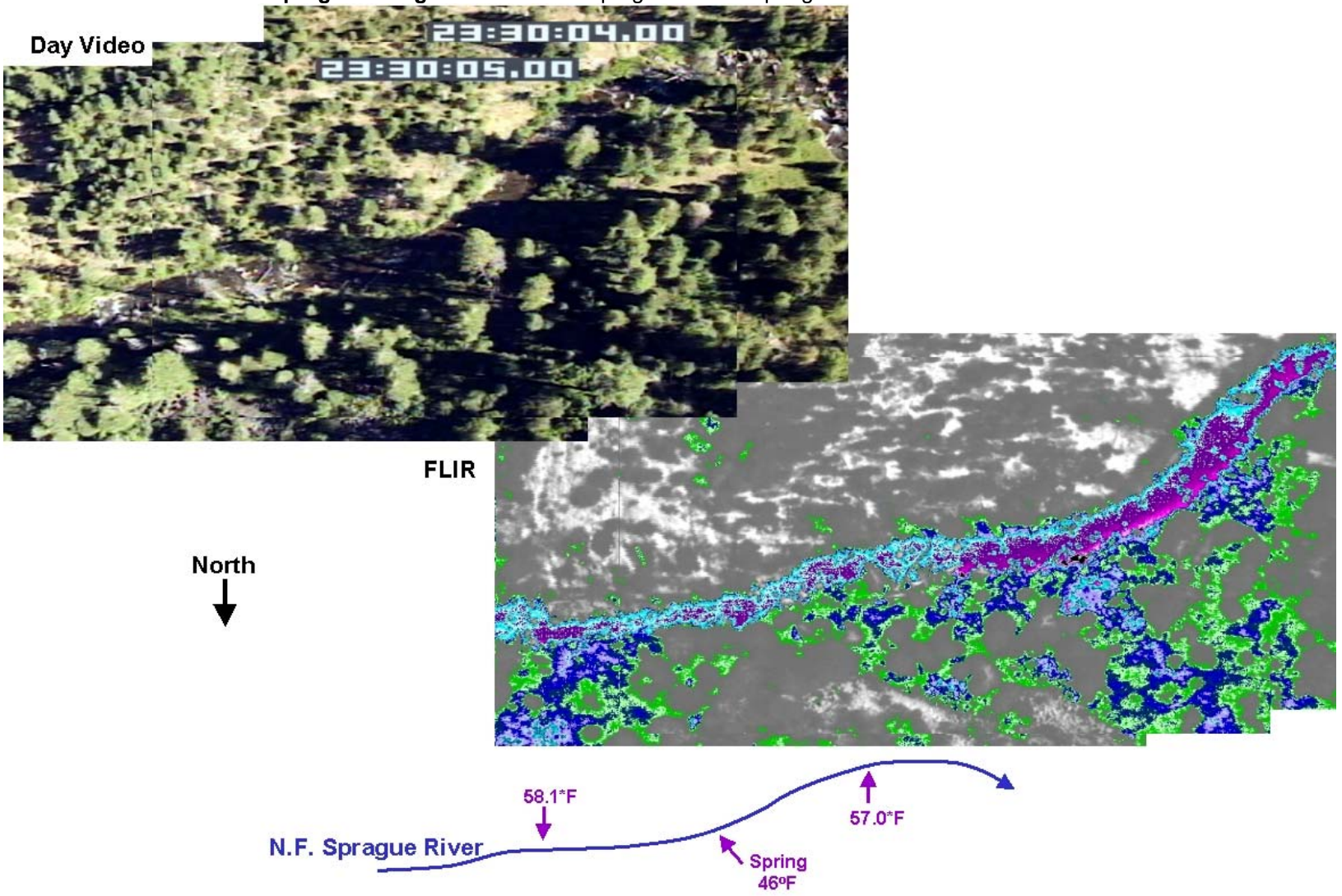
Timber Harvest
Higher Surface Temperatures Indicate
Warmer Microclimate

Since the direction of flow is south, both stream banks have similar levels of solar exposure

FLIR Derived Temperature (°F) - August 16, 1999 (4:20 PM to 4:44 PM)



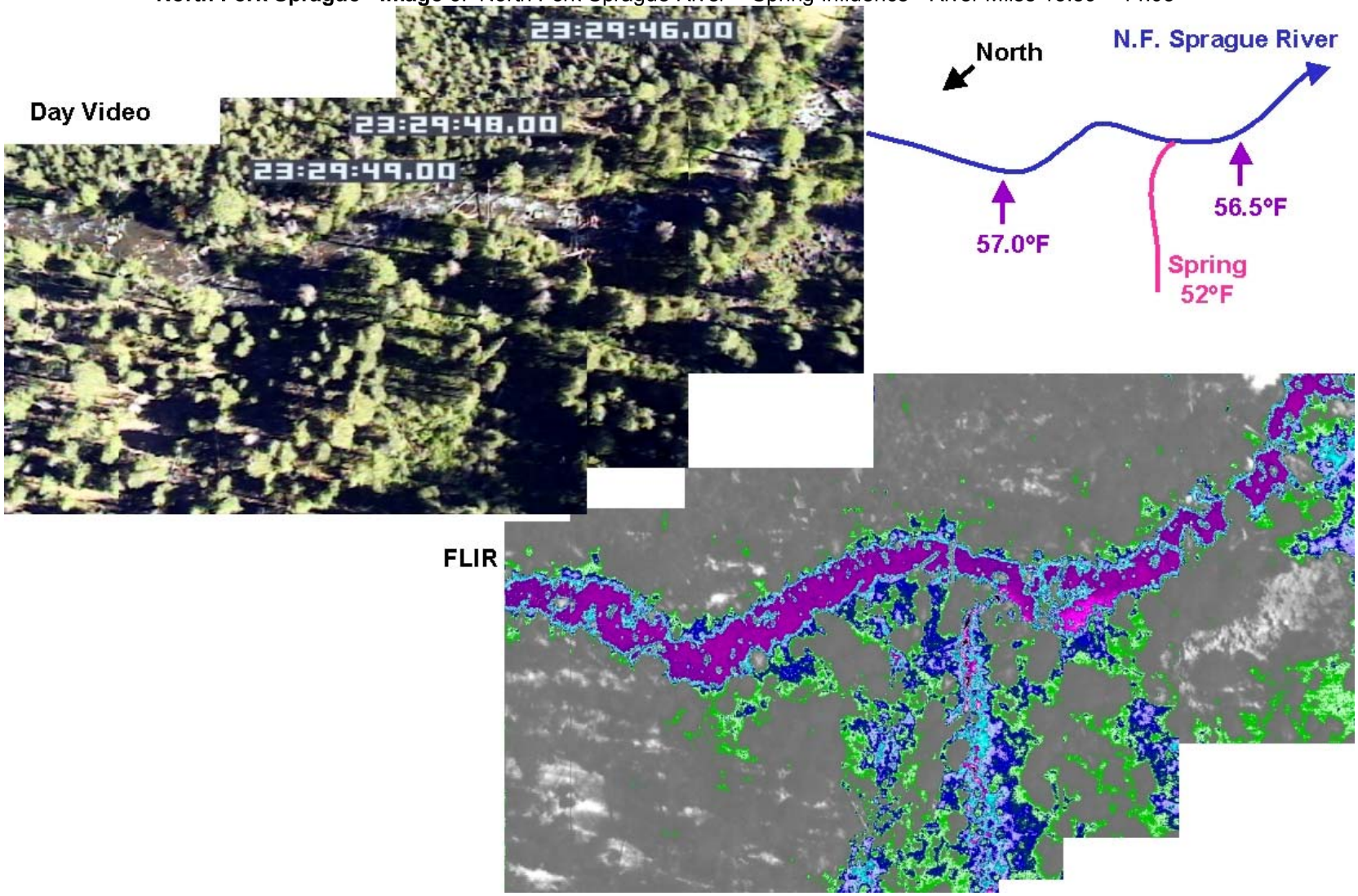
North Fork Sprague - Image 5. North Fork Sprague River – Spring Influence - River Miles 14.41 to 14.47



FLIR Derived Temperature (°F) - August 16, 1999 (4:20 PM to 4:44 PM)



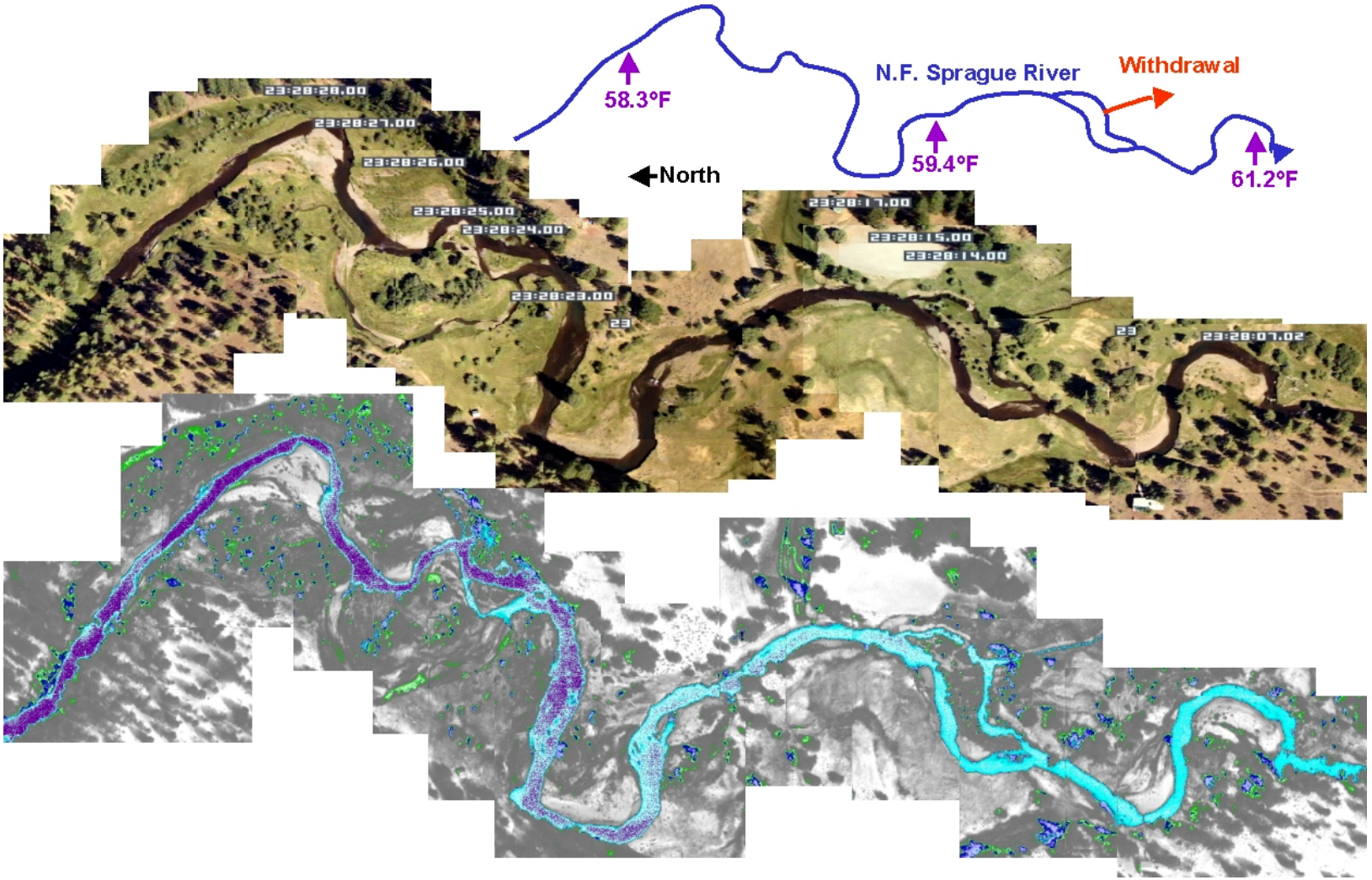
North Fork Sprague - Image 6. North Fork Sprague River - Spring Influence - River Miles 13.89 – 14.03



FLIR Derived Temperature (°F) - August 16, 1999 (4:20 PM to 4:44 PM)

<50 | 50 | 52 | 54 | 55 | 57 | 59 | 61 | 63 | 64 | 66 | 68 | 70 | 72 | 73 | 75 | 81 | 83 | 85 →

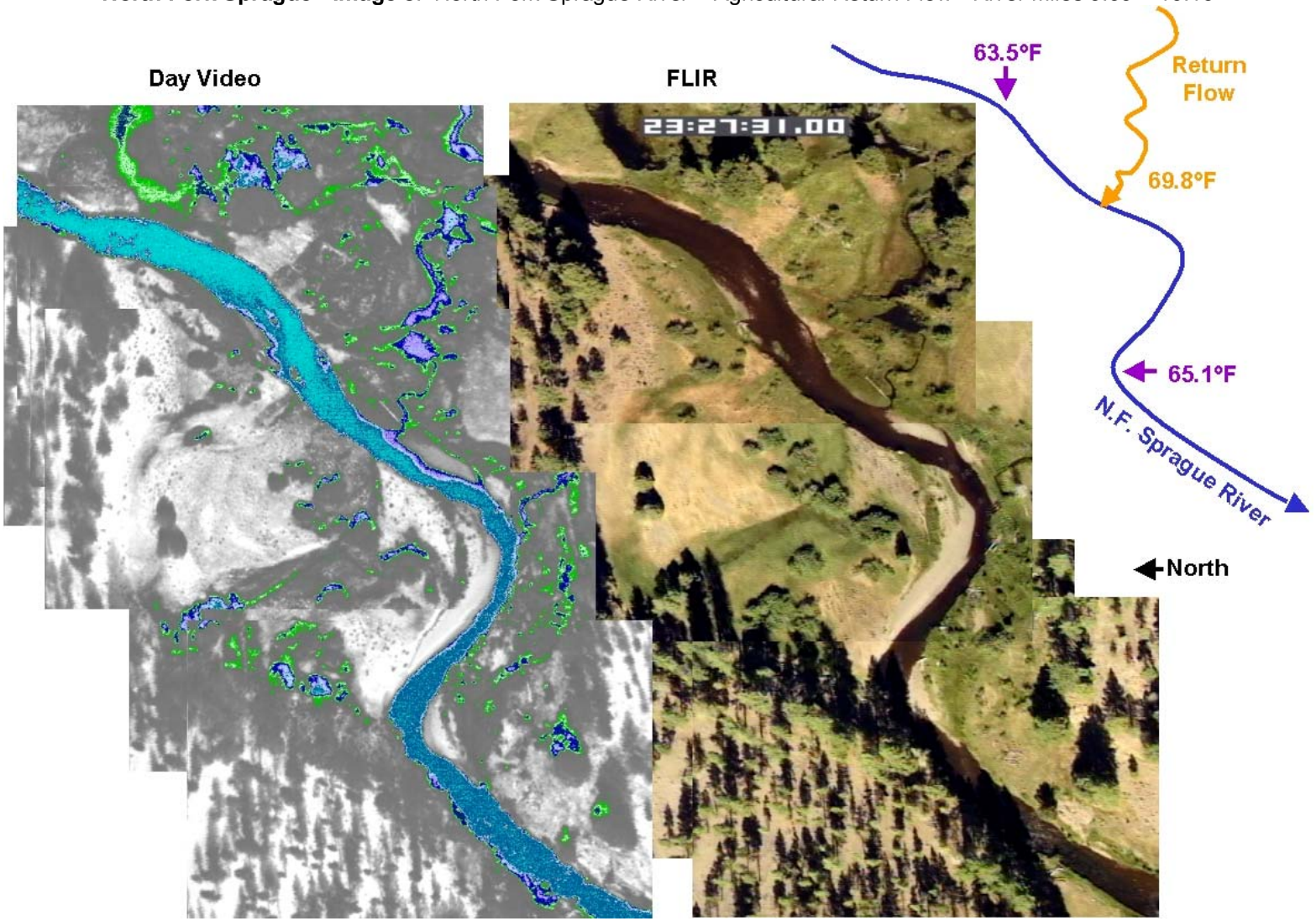
North Fork Sprague - Image 7. North Fork Sprague River – Channel Disturbance and Water Withdrawal - River Miles 10.70 – 11.36



FLIR Derived Temperature (°F) - August 16, 1999 (4:20 PM to 4:44 PM)

<50	50	52	54	55	57	59	61	63	64	66	68	70	72	73	75	81	83	85

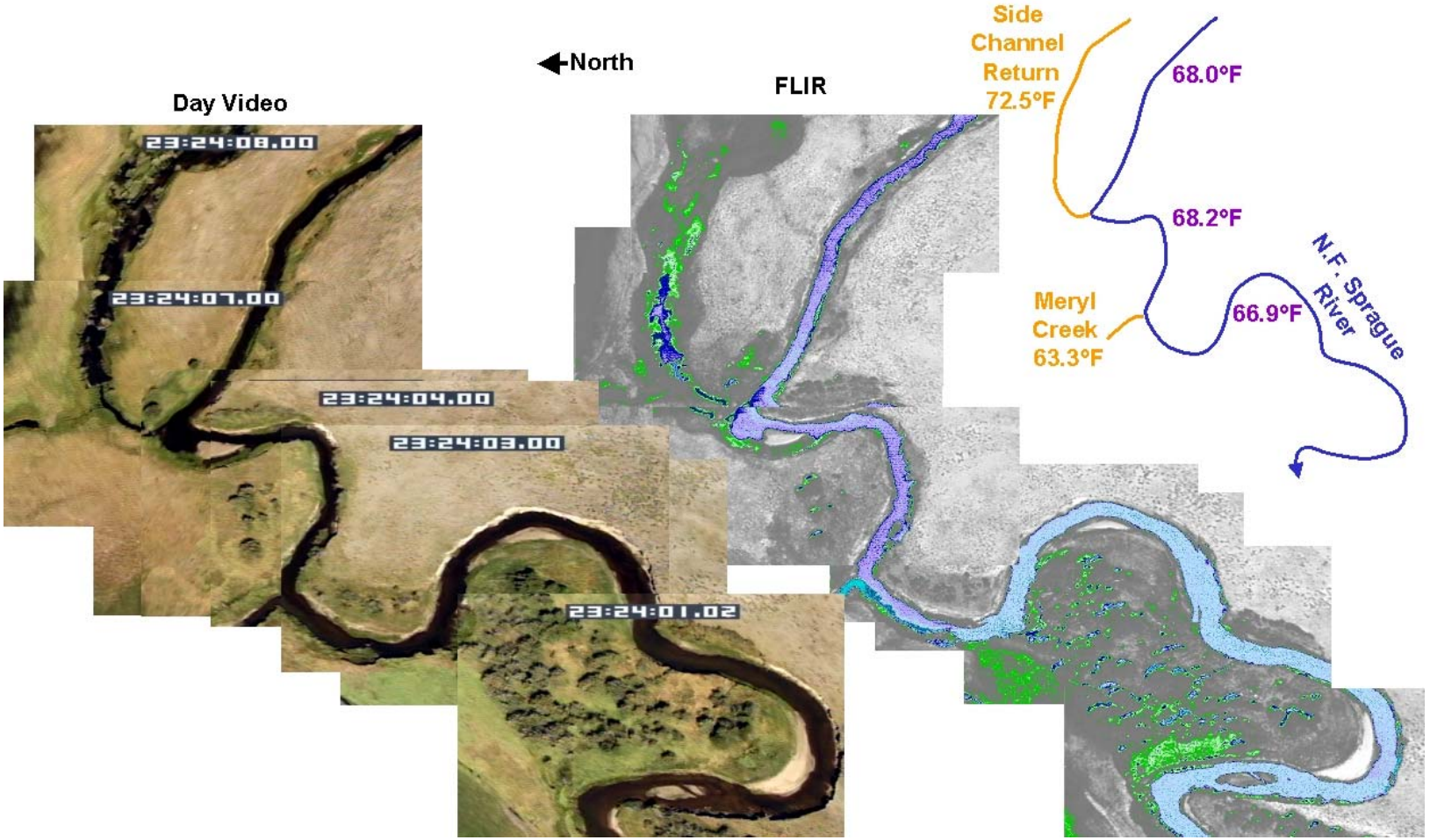
North Fork Sprague - Image 8. North Fork Sprague River – Agricultural Return Flow - River Miles 9.99 – 10.16



FLIR Derived Temperature (°F) - August 16, 1999 (4:20 PM to 4:44 PM)



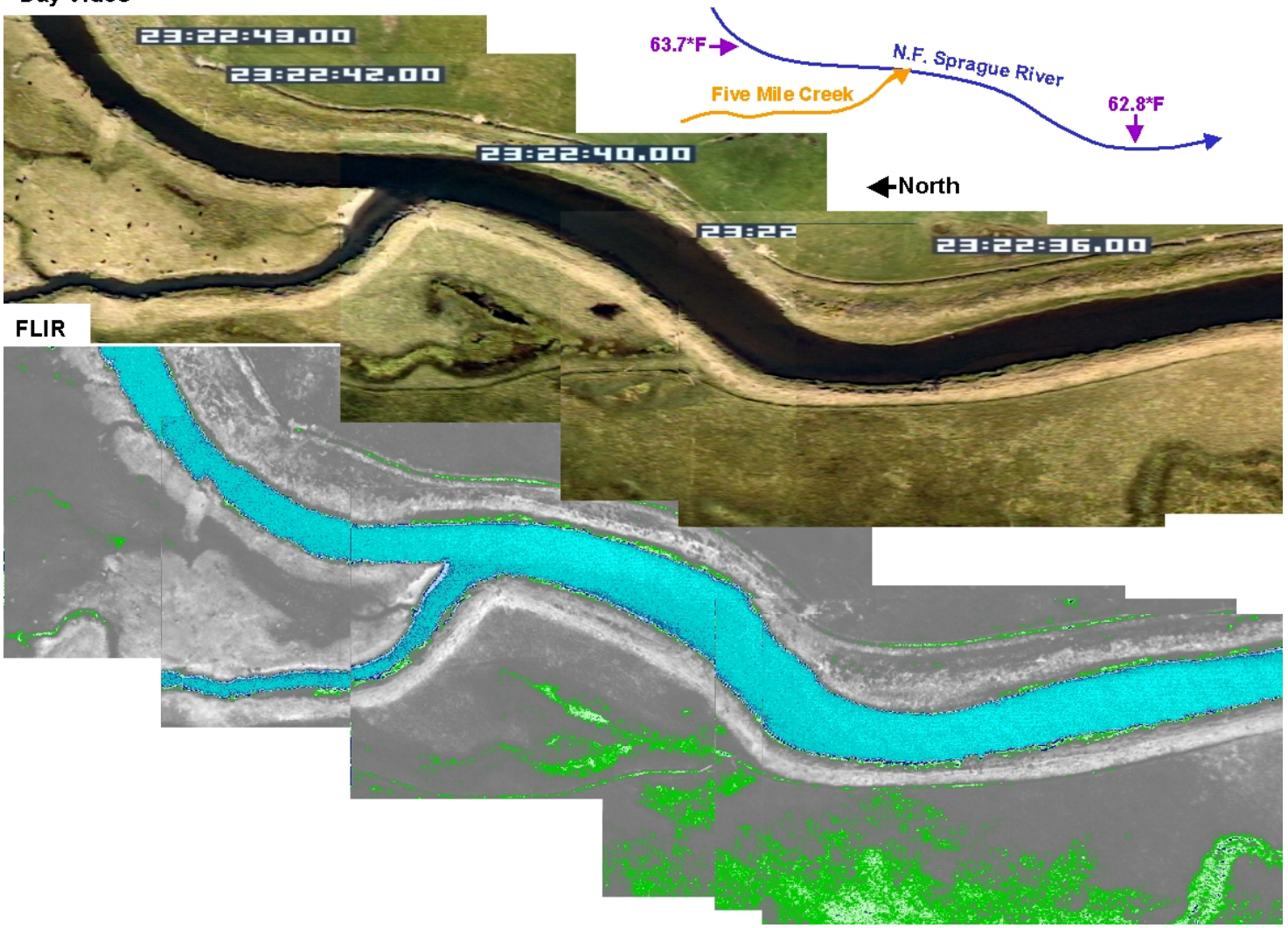
North Fork Sprague - Image 9. North Fork Sprague River – Return Flow and Meryl Creek Confluence - River Miles 5.04 – 5.51



FLIR Derived Temperature (°F) - August 16, 1999 (4:20 PM to 4:44 PM)



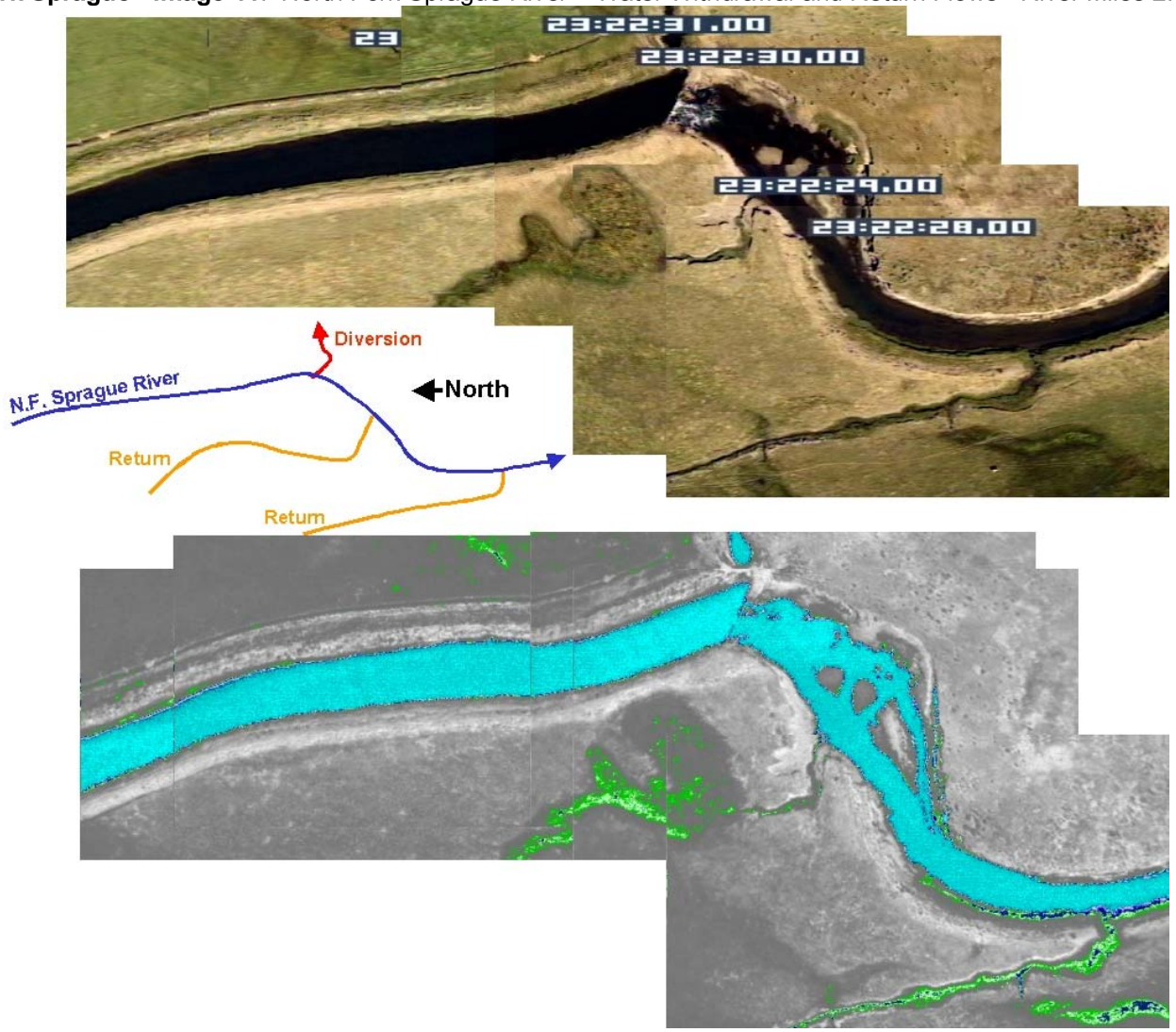
North Fork Sprague - Image 10. North Fork Sprague River - Five Mile Creek Confluence - River Miles 2.61 – 2.72



FLIR Derived Temperature (°F) - August 16, 1999 (4:20 PM to 4:44 PM)



North Fork Sprague - Image 11. North Fork Sprague River – Water Withdrawal and Return Flows - River Miles 2.30 – 2.38



FLIR Derived Temperature (°F) - August 16, 1999 (4:20 PM to 4:44 PM)



2.2.5.5 South Fork Sprague River FLIR Derived Longitudinal Heating and Imagery

South Fork Sprague River longitudinal temperatures were sampled using FLIR on August 12, 1999 from 4:04 to 4:31 PM. **Figure 2-26** shows the FLIR flight path – color coded to represent the measured stream temperature. A general stream heating trend from about 50°F at the headwaters (river mile 32) to 73°F at the mouth (river mile 0) is apparent from **Figure 2-26**. Examination of the longitudinal temperature profile (**Figure 2-27**) and actual infrared and day television images reveals the smaller scale variability of the South Fork Sprague River temperatures. Compared to the North Fork, the South Fork Sprague River exhibits less longitudinal temperature variability.

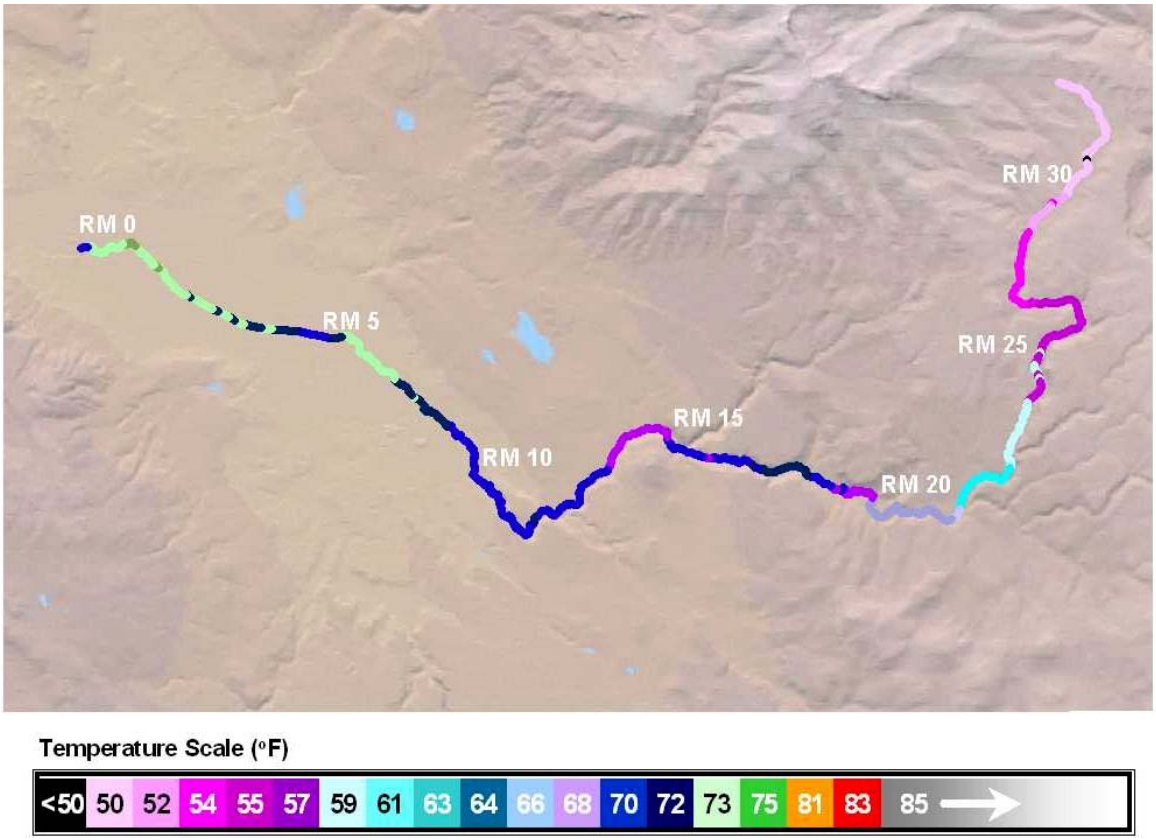


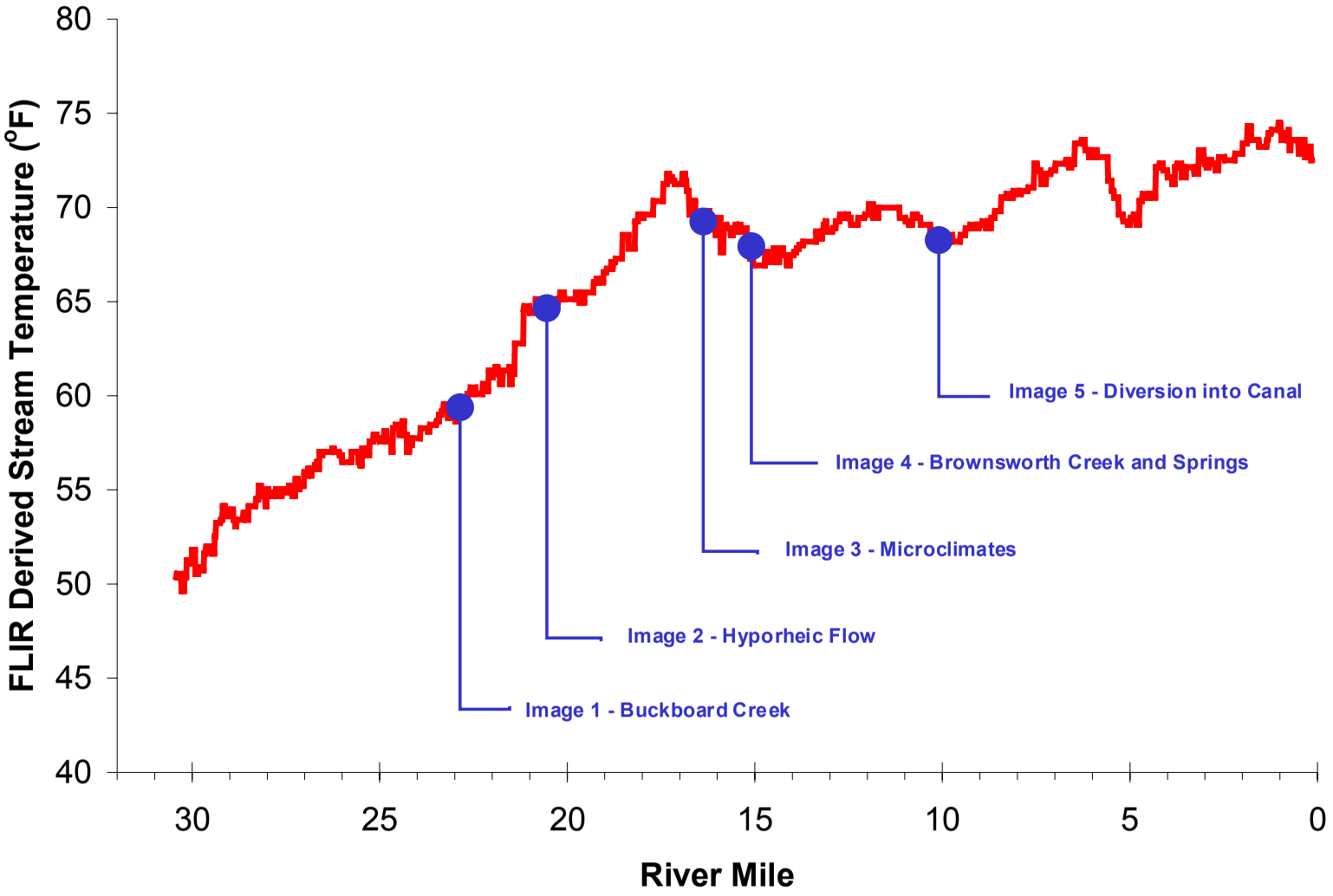
***Figure 2-26**. South Fork Sprague River Sampled FLIR Temperatures*

The South Fork Sprague River gradually heats from 50°F to 72°F from the headwaters to river mile 17. The river then enters a v-shaped valley and is flowing westward through an area with moderate topographic shade, confined channels, and shade from near stream land cover. Associated longitudinal stream cooling temperature stabilization results. Starting at river mile 10 a heating gradient gradually increase the stream temperatures in the longitudinal direction. Below river mile 10, the South Fork Sprague River flows through low gradient highly managed lands where straightened/downcut channels, irrigation returns and diversions are common. These lower 10 river miles continue to heat, reaching 75°F in some areas.

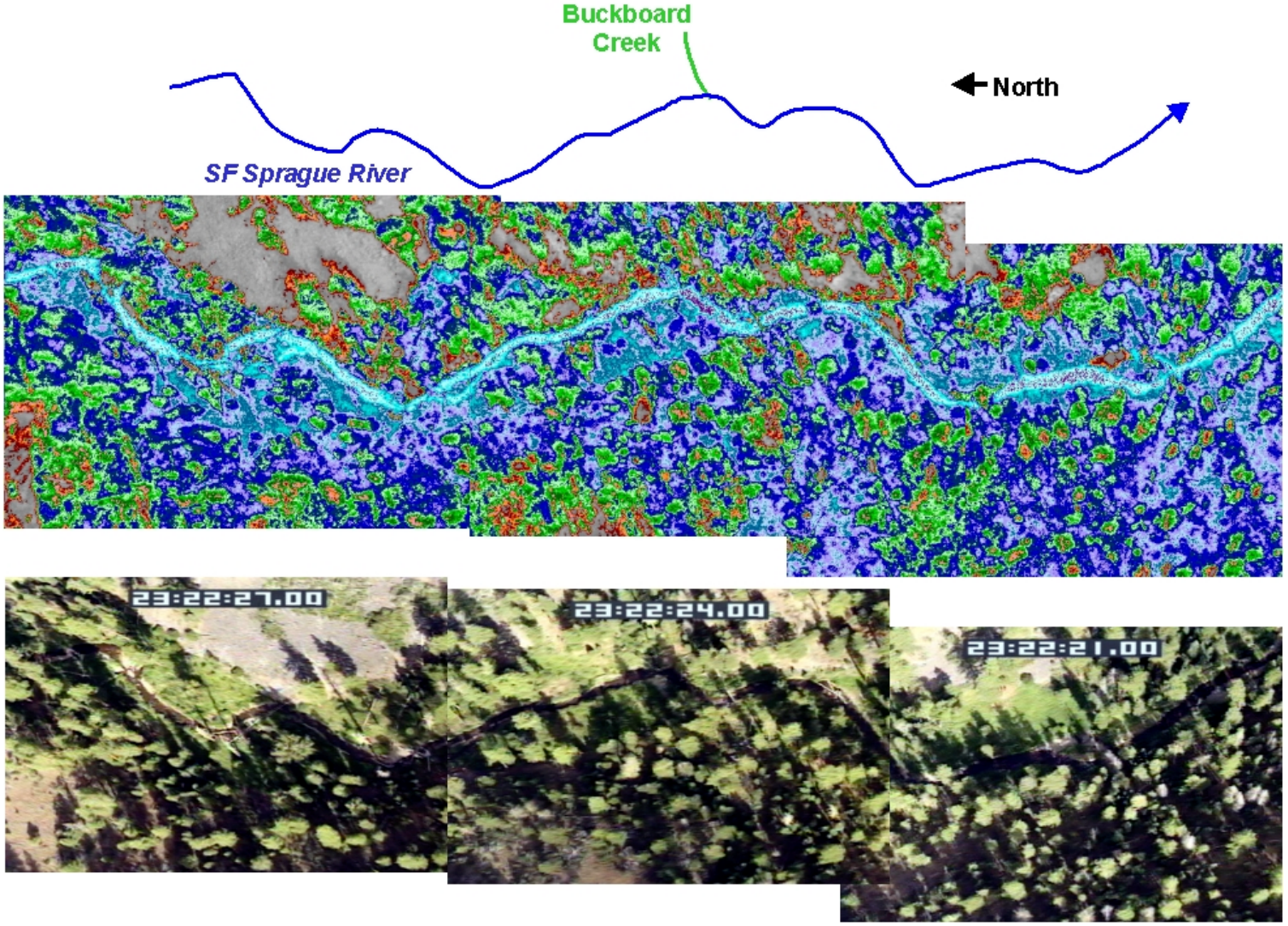
Summary of Selected FLIR Imagery - South Fork Sprague River

- **South Fork Sprague River - Image 1**. South Fork Sprague River – Buckboard Creek Confluence – River Miles 23.10 to 22.91. Midway through the reach displayed in this image, Buckboard Creek enters on the left bank of the South Fork Sprague River. Buckboard Creek enters at about 57°F, creating a visible plume of cooler water in the South Fork Sprague River.
- **South Fork Sprague River - Image 2**. South Fork Sprague River – Hyporheic Flow – River Miles 20.8 to 20.6. This image shows a location where some of the stream flows beneath the surface of a gravel bar (part of a side channel) and re-surfaces cooler than it was upstream.
- **South Fork Sprague River - Image 3**. South Fork Sprague River - Microclimates – River Miles 16.07 to 15.91. The north-facing slope in this image is much cooler than the south facing slope of the valley. The south-facing slope has relatively little woody vegetation, but there is a patch near the stream that is markedly cooler in temperature.
- **South Fork Sprague River - Image 4**. South Fork Sprague River – Brownsworth Creek and Springs – River Miles 15.35 to 15.02. Brownsworth Creek is having a significant cooling effect on the South Fork Sprague River, dropping its temperature from 68°F to 66°F. Just downstream of the Brownsworth Creek confluence are some unmapped springs, which further cool down the South Fork Sprague River.
- **South Fork Sprague River - Image 5**. South Fork Sprague River – Diversion Canal – River Miles 10.14 to 9.78. At this location, is a major irrigation diversion. It appears as though the South Fork Sprague River channel has undergone anthropogenic modification in order create a pool for the diversion. This is the first of many major diversions and channel modifications characteristic of the South Fork Sprague River and the Sprague River mainstem.

Figure 2-27. South Fork Sprague River FLIR Derived Temperatures - August 12, 1999 - 4:04 to 4:31 PM



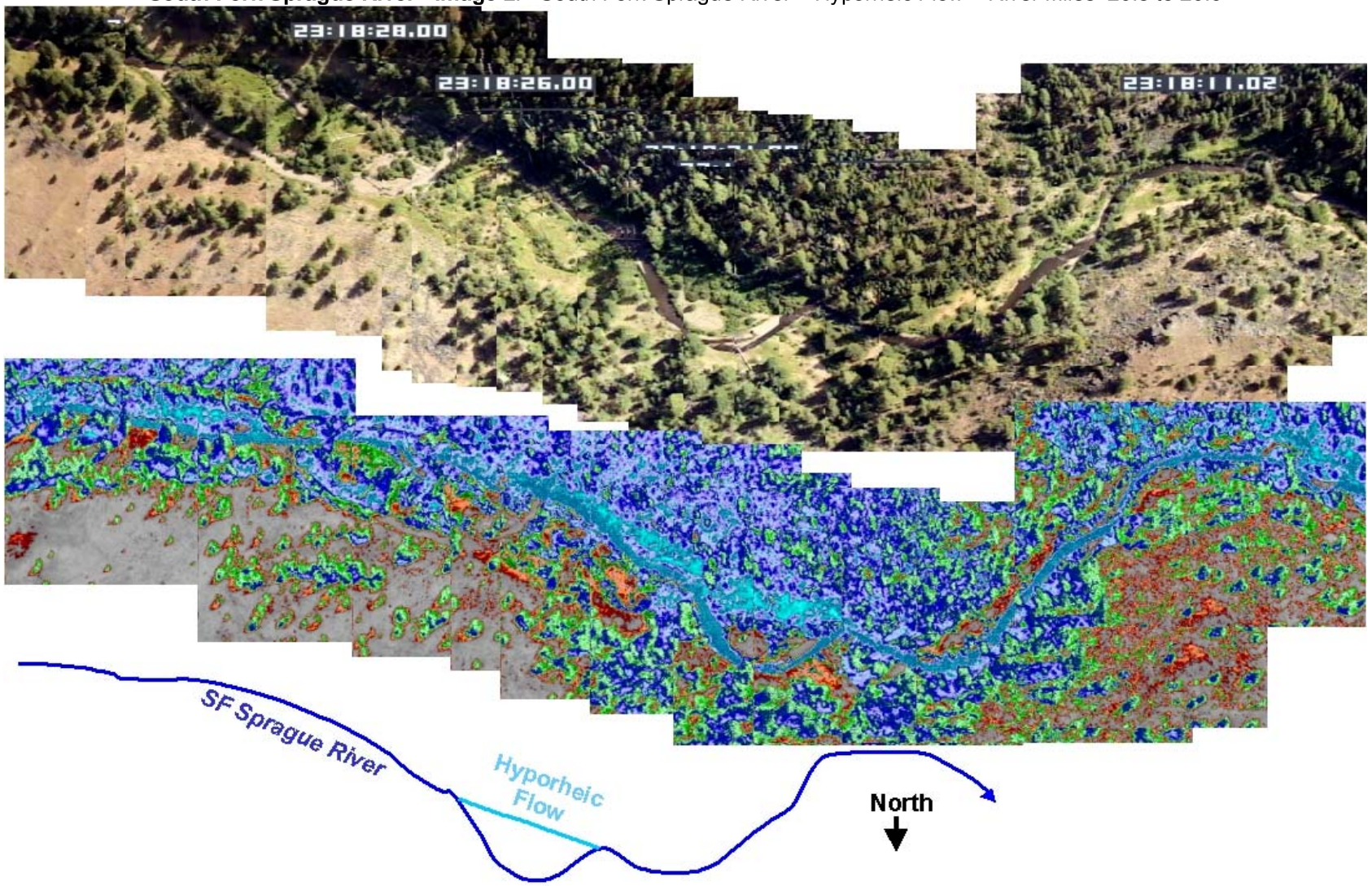
South Fork Sprague River - Image 1. South Fork Sprague River – Buckboard Creek Confluence – River Miles 23.10 to 22.91



FLIR Derived Temperature (°F) - August 12, 1999 (4:04 to 4:31 PM)



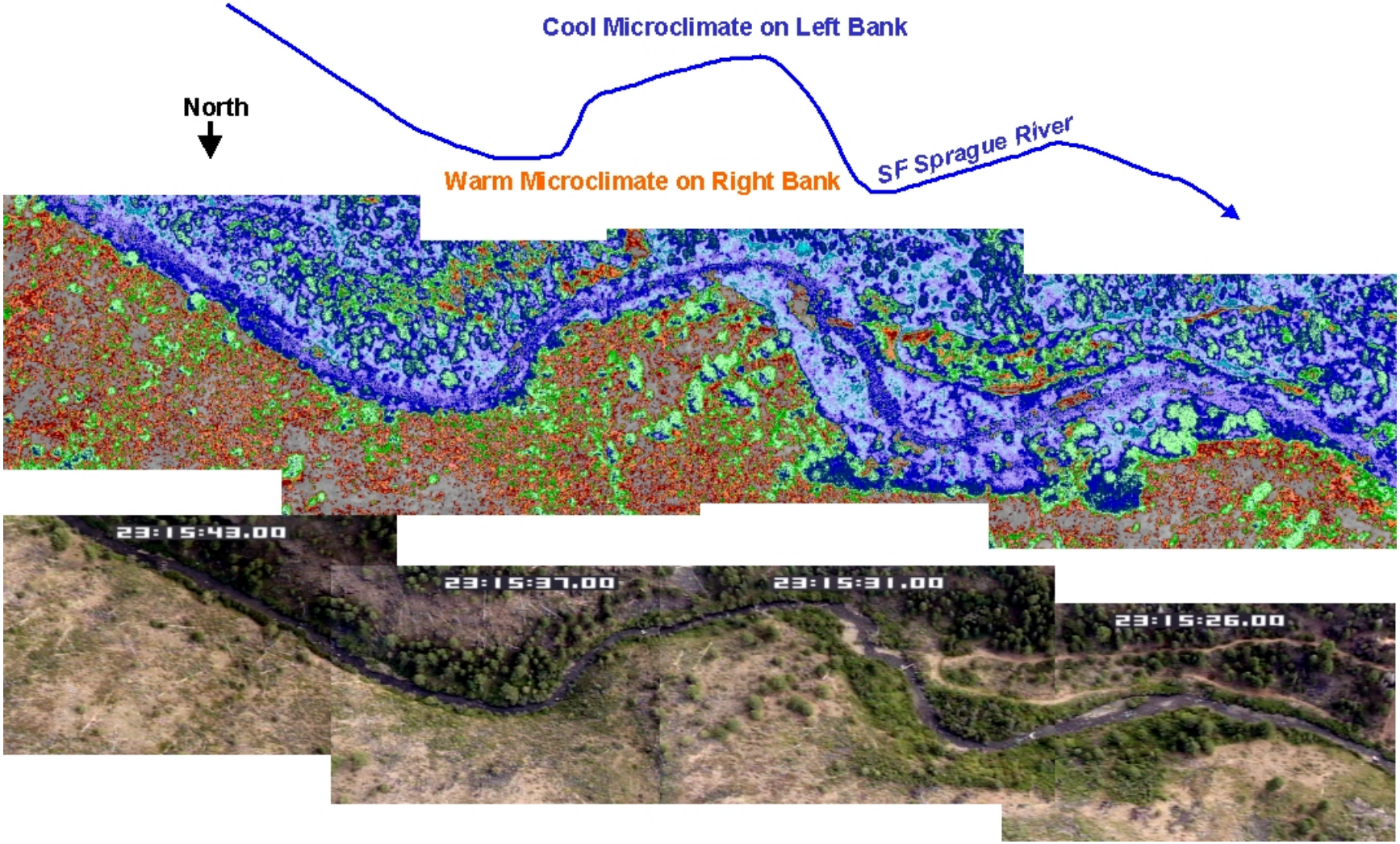
South Fork Sprague River - Image 2. South Fork Sprague River – Hyporheic Flow – River Miles 20.8 to 20.6



FLIR Derived Temperature (°F) - August 12, 1999 (4:04 to 4:31 PM)



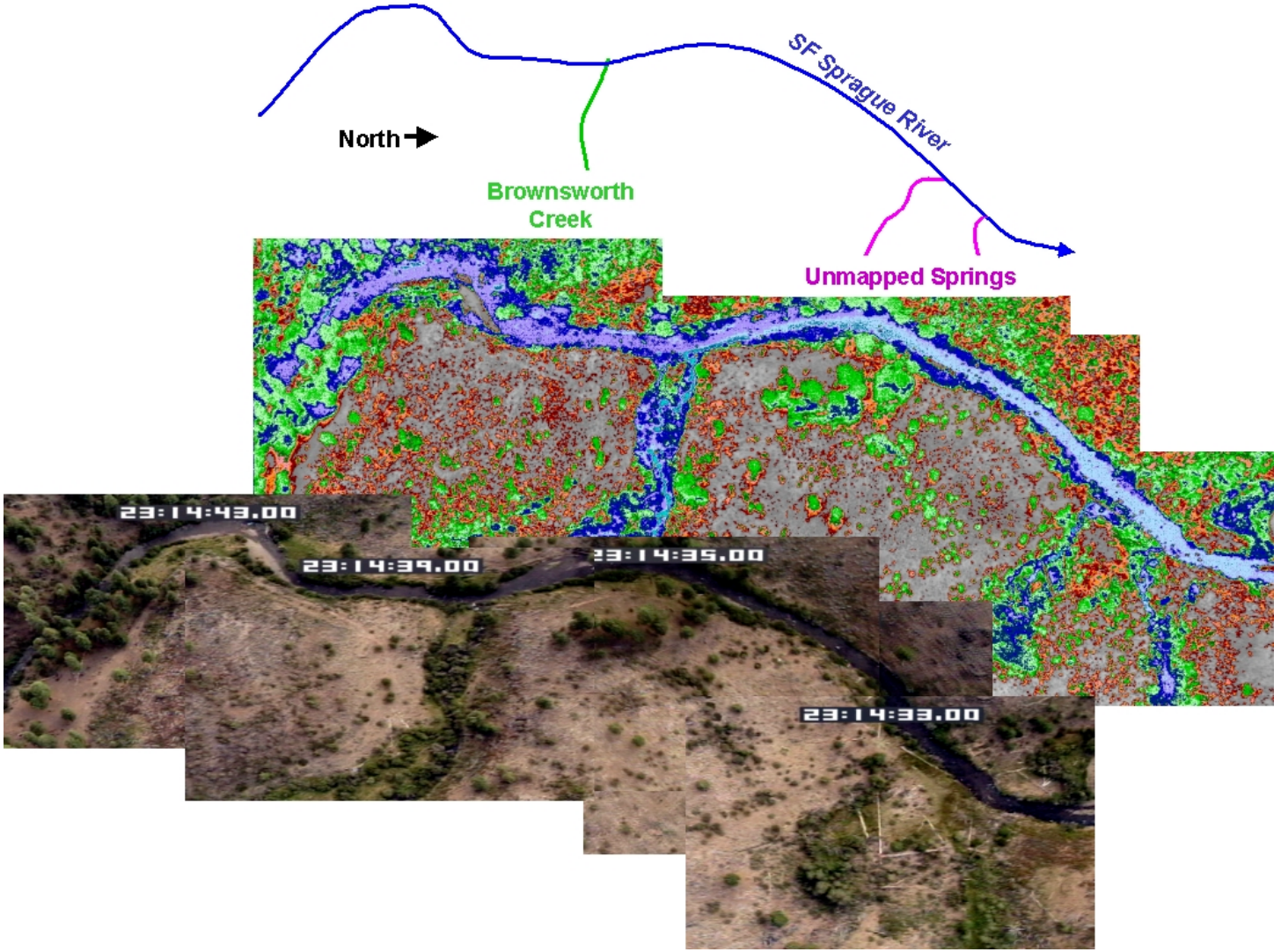
South Fork Sprague River - Image 3. South Fork Sprague River - Microclimates – River Miles 16.07 to 15.91



FLIR Derived Temperature (°F) - August 12, 1999 (4:04 to 4:31 PM)



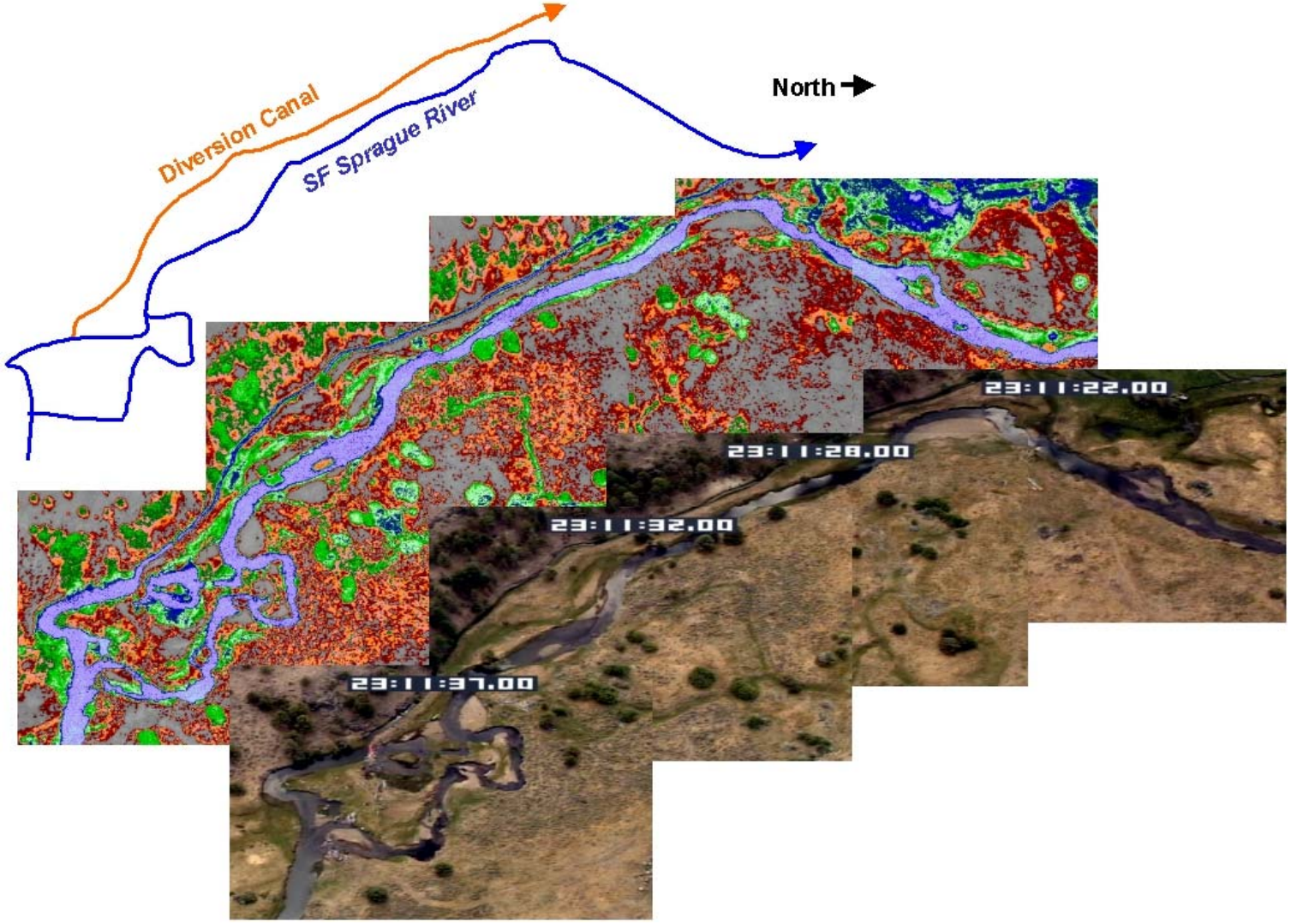
South Fork Sprague River - Image 4. South Fork Sprague River – Brownsworth Creek and Springs – River Miles 15.35 to 15.02



FLIR Derived Temperature (°F) - August 12, 1999 (4:04 to 4:31 PM)



South Fork Sprague River - Image 5. South Fork Sprague River – Diversion Canal – River Miles 10.14 to 9.78



FLIR Derived Temperature (°F) - August 12, 1999 (4:04 to 4:31 PM)



2.2.5.6 Fishhole Creek FLIR Derived Longitudinal Heating and Imagery

Fishhole Creek longitudinal temperatures were sampled using forward looking infrared radiometry (FLIR) on August 12, 1999 from 4:42 to 4:57 PM. **Figure 2-28** shows the FLIR flight path – color coded to display the measured stream temperature. Note that only river miles 0 through 19.0 were sampled. The length of Fishhole Creek that was sampled with FLIR was over 70°F, and even into the 80°F range. **Figure 2-29** shows the longitudinal variability of the stream temperature.

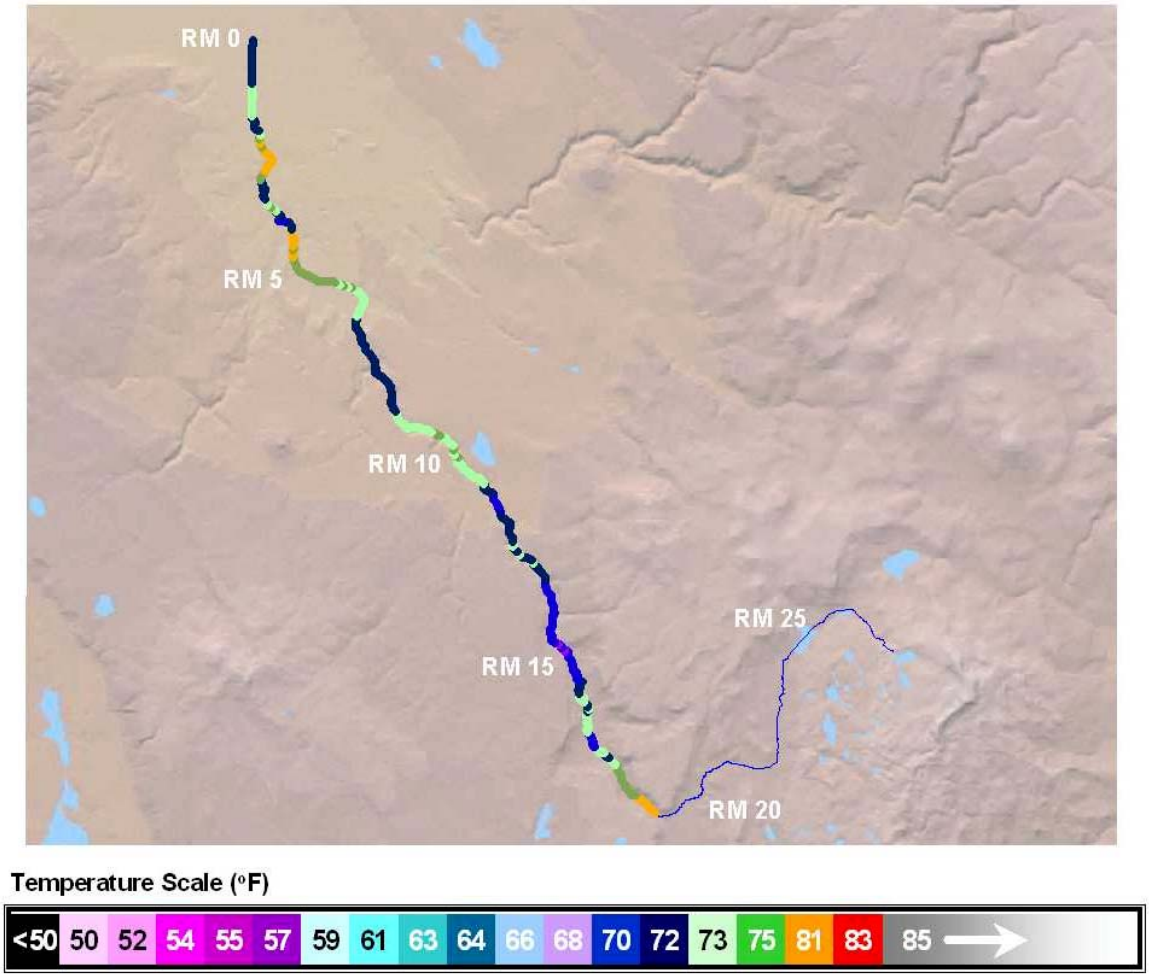


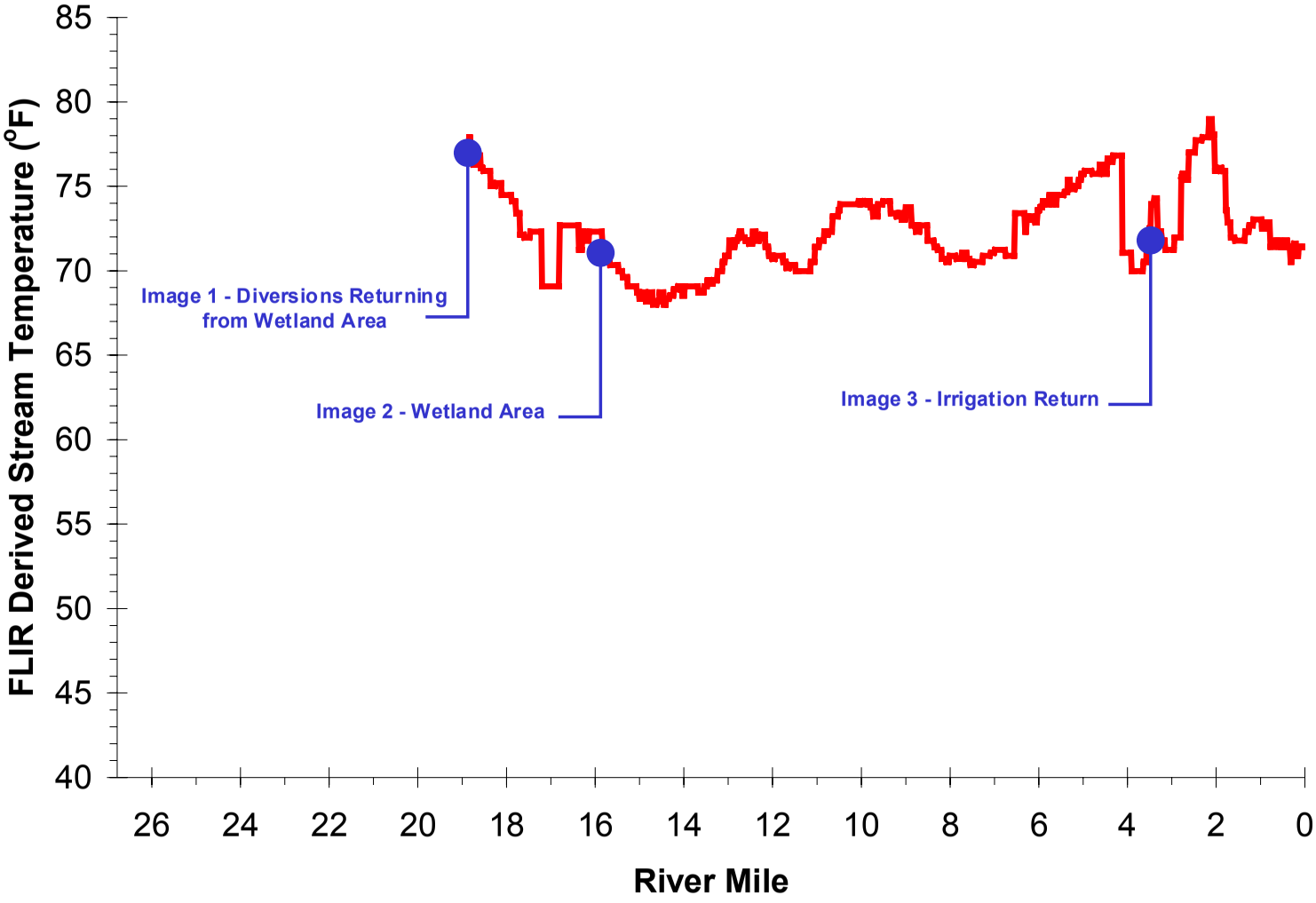
***Figure 2-28**. Fishhole Creek Sampled FLIR Temperatures*

At river mile 19.0, extremely warm (i.e., over 80°F) agriculture return flows are responsible for the hot temperatures seen on in this stream segment. Fishhole Creek flows through some wetland areas and loses heat until approximately river mile 15.0. There is a wetland area at river mile 17.0 where the channel splits and the stream temperature rapidly drops from 73°F to 69°F. However, temperatures throughout the sampled area are consistently warm. Stream temperatures vary greatly in the lower 4.0 river miles due to extensive near stream and channel modifications, points of diversion, and irrigation return flows. At river mile 3.5 a large irrigation return heats the stream from 69°F to 73°F.

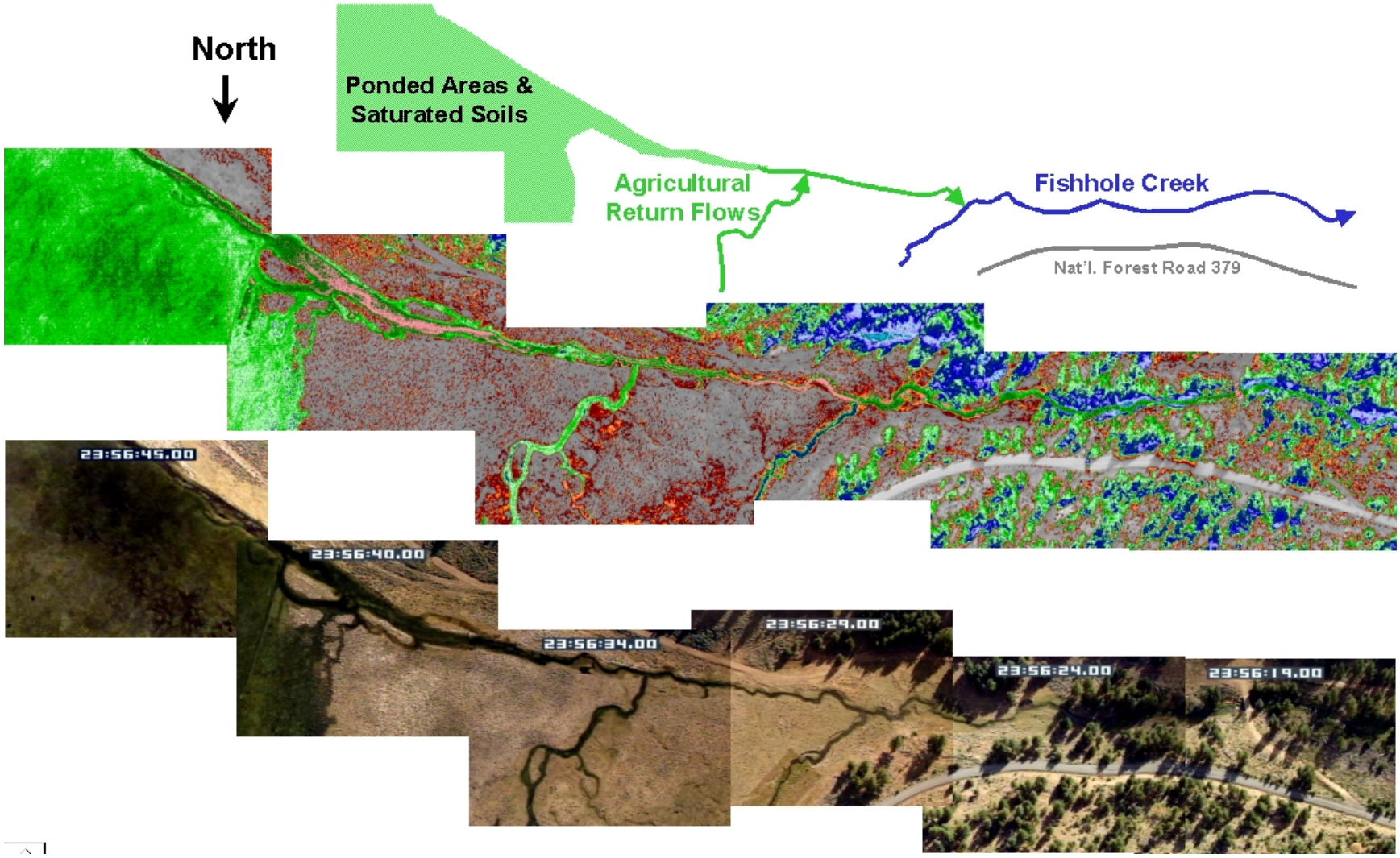
Summary of Selected FLIR Imagery - Fishhole Creek

- **Fishhole - Image 1**. Fishhole Creek – Diversions Returning from Wetland Area – River Miles 19.17 to 19.0. This is the upper extent of the FLIR survey. Upstream of this image (river mile 19.98) there is a large diversion canal, that guides much of the Fishhole Creek flow to a saturated and/or agricultural area. The upper left corner of the imagery shows saturated area, with channels of warm water leading to the Fishhole Creek mainstem. It appears as though there is a large volume in the returning channels, relative to Fishhole Creek.
- **Fishhole - Image 2.** Fishhole Creek – Wetland Area – River Miles 15.74 to 15.28. This imagery exemplifies some of the characteristic wetlands that Fishhole Creek flows through. The immediately surrounding floodplain is saturated and remains cool. Fishhole Creek cools a few degrees as it flows a through this reach.
- **Fishhole - Image 3**. Fishhole Creek – Unmapped Spring – River Miles 3.60 to 3.40. In the upper left corner of the imagery is a railroad grade that guides Fishhole Creek to flow northwestward. There is a minor channel that circumvents the railroad grade and rejoins the mainstem just downstream of the railroad grade. On the left bank is what appears to be an irrigation return, which warms the stream temperature from 69°F to 73°F.

Figure 2-29. Fishhole Creek FLIR Derived Temperatures - August 12, 1999 - 4:42 to 4:57 PM



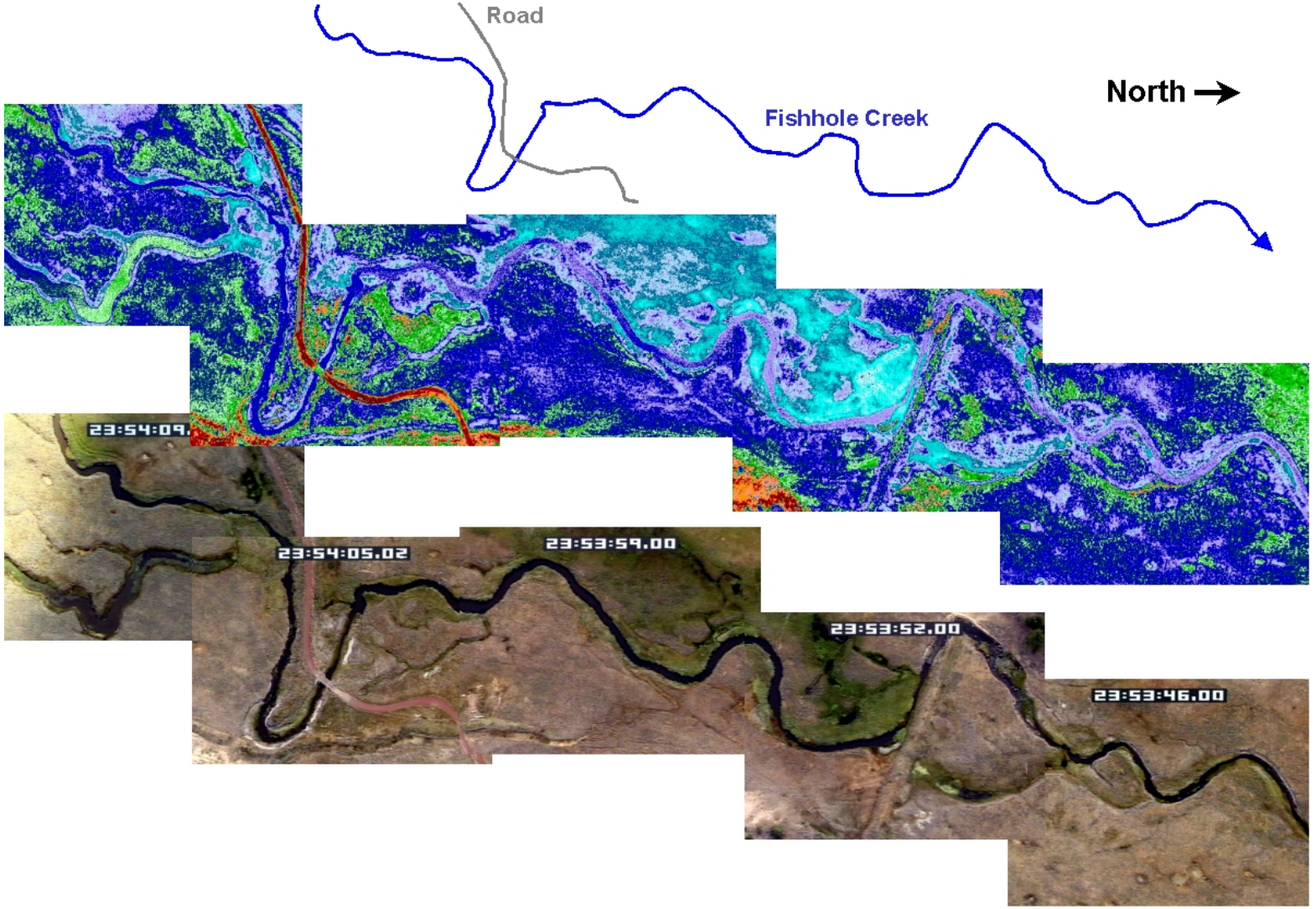
Fishhole - Image 1. Fishhole Creek – Diversions Returning from Wetland Area – River Miles 19.17 to 19.0.



FLIR Derived Temperature (°F) - August 12, 1999 (4:42 to 4:57 PM)

<50 | 50 | 52 | 54 | 55 | 57 | 59 | 61 | 63 | 64 | 66 | 68 | 70 | 72 | 73 | 75 | 81 | 83 | 85 →

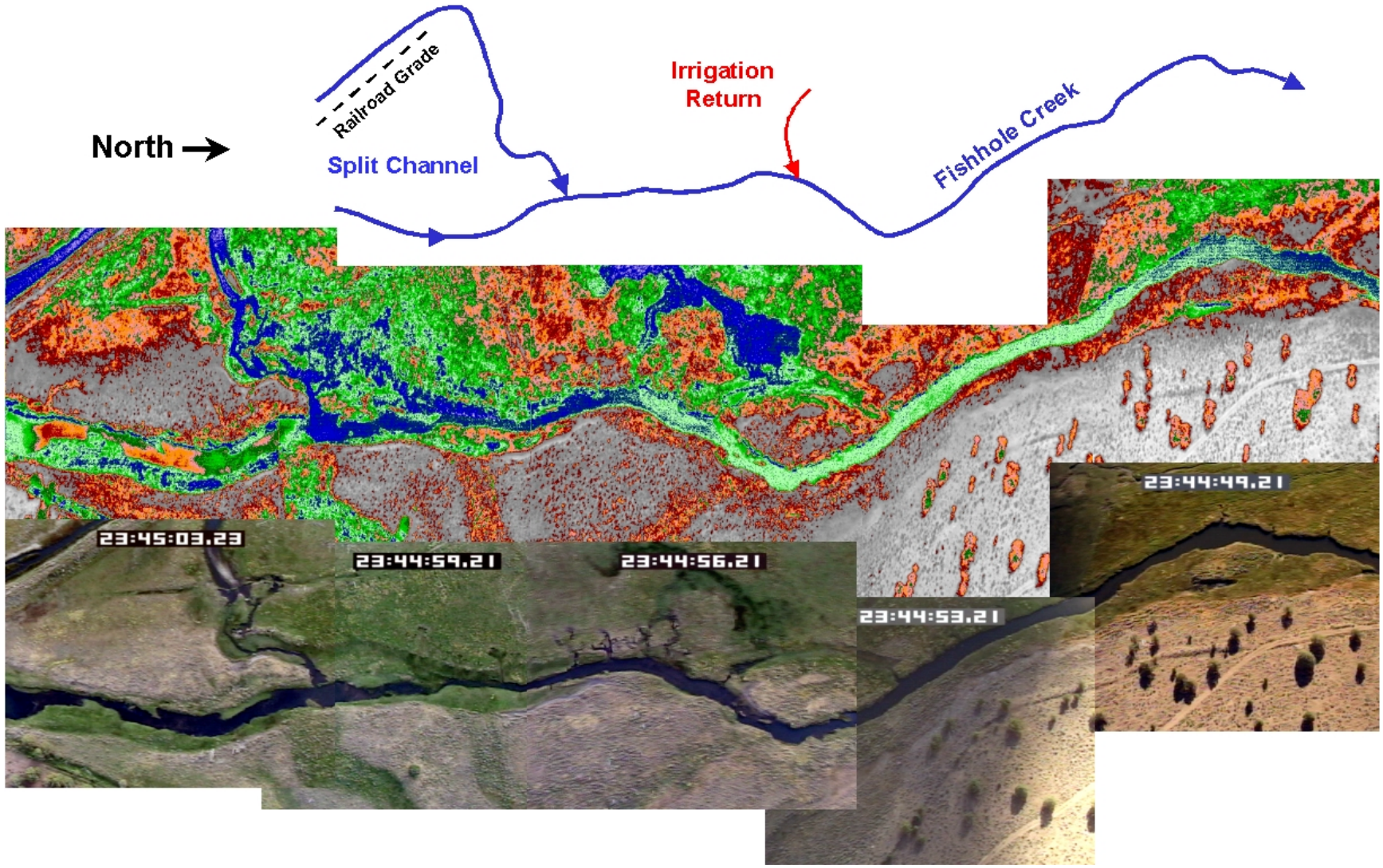
Fishhole - Image 2. Fishhole Creek – Wetland Area – River Miles 15.74 to 15.28.



FLIR Derived Temperature (°F) - August 12, 1999 (4:42 to 4:57 PM)



Fishhole - Image 3. Fishhole Creek – Irrigation Return – River Miles 3.60 to 3.40.



FLIR Derived Temperature (°F) - August 12, 1999 (4:42 to 4:57 PM)

<50 | 50 | 52 | 54 | 55 | 57 | 59 | 61 | 63 | 64 | 66 | 68 | 70 | 72 | 73 | 75 | 81 | 83 | 85 →

2.2.6 Point Source Type/Location Data

Point Source Type/Location Data are used in this analysis to:

- *Map stream NPDES[11] and other point sources, and develop waste load allocations.*

The Oregon Department of Environmental Quality maintains a database for point source information. This data was used to place point sources within the Upper Klamath Lake drainage. Five point sources discharge to waters with in the Upper Klamath Lake drainage:

1. Crooked Creek Hatchery discharges into Crooked Creek at RM 5.6
2. Chiloquin Sewage Treatment Plant discharges to Williamson River at RM 11.8
3. Specialty Fiber Products discharges into a pond.
4. Klamath Veneer dumps into Upper Klamath Lake.
5. Jeld-Wen also dumps into Upper Klamath Lake.

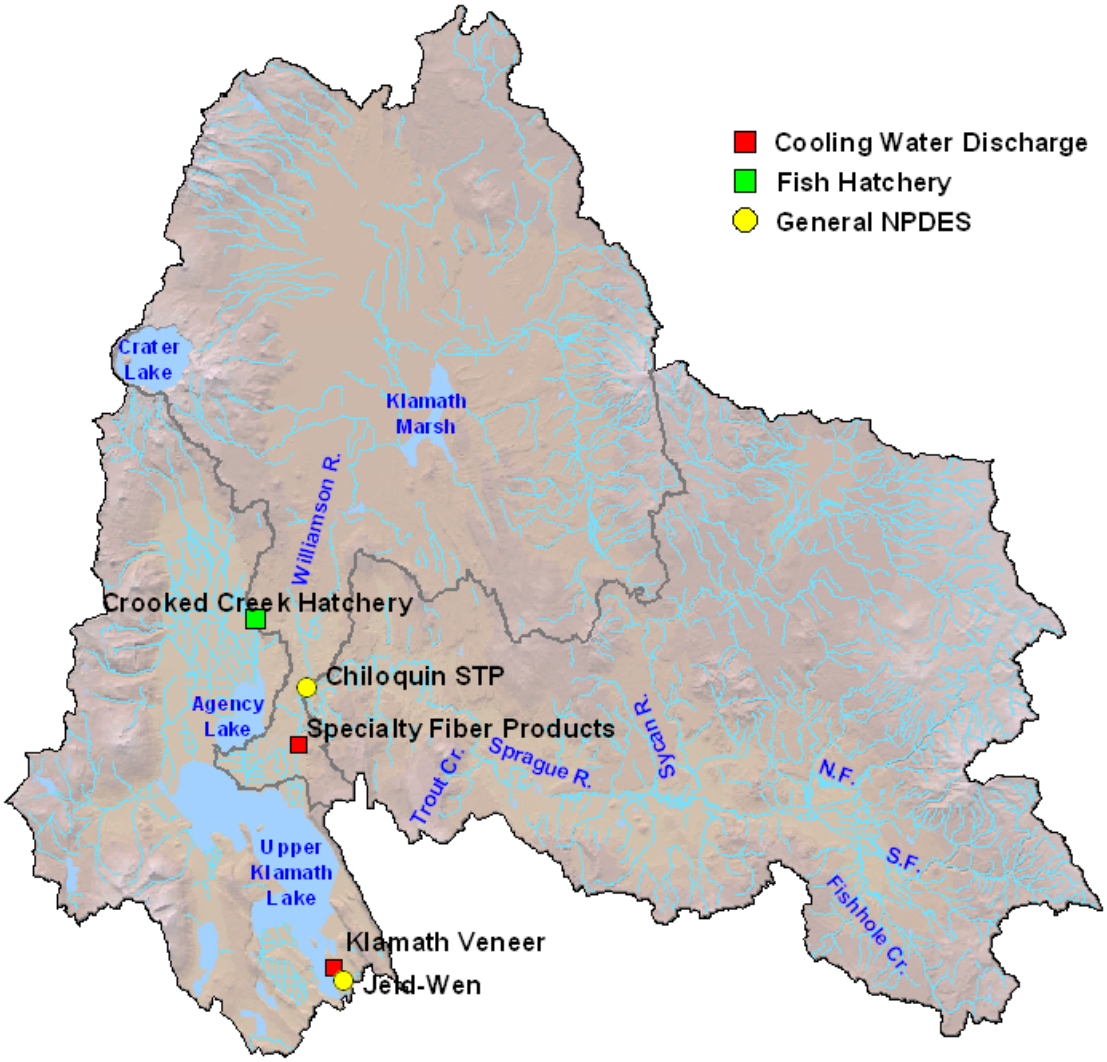


Figure 2-30. Point sources of heat

[11] National Pollutant Discharge Elimination System established by the CWA

CHAPTER 3. DERIVED DATA AND SAMPLED PARAMETERS

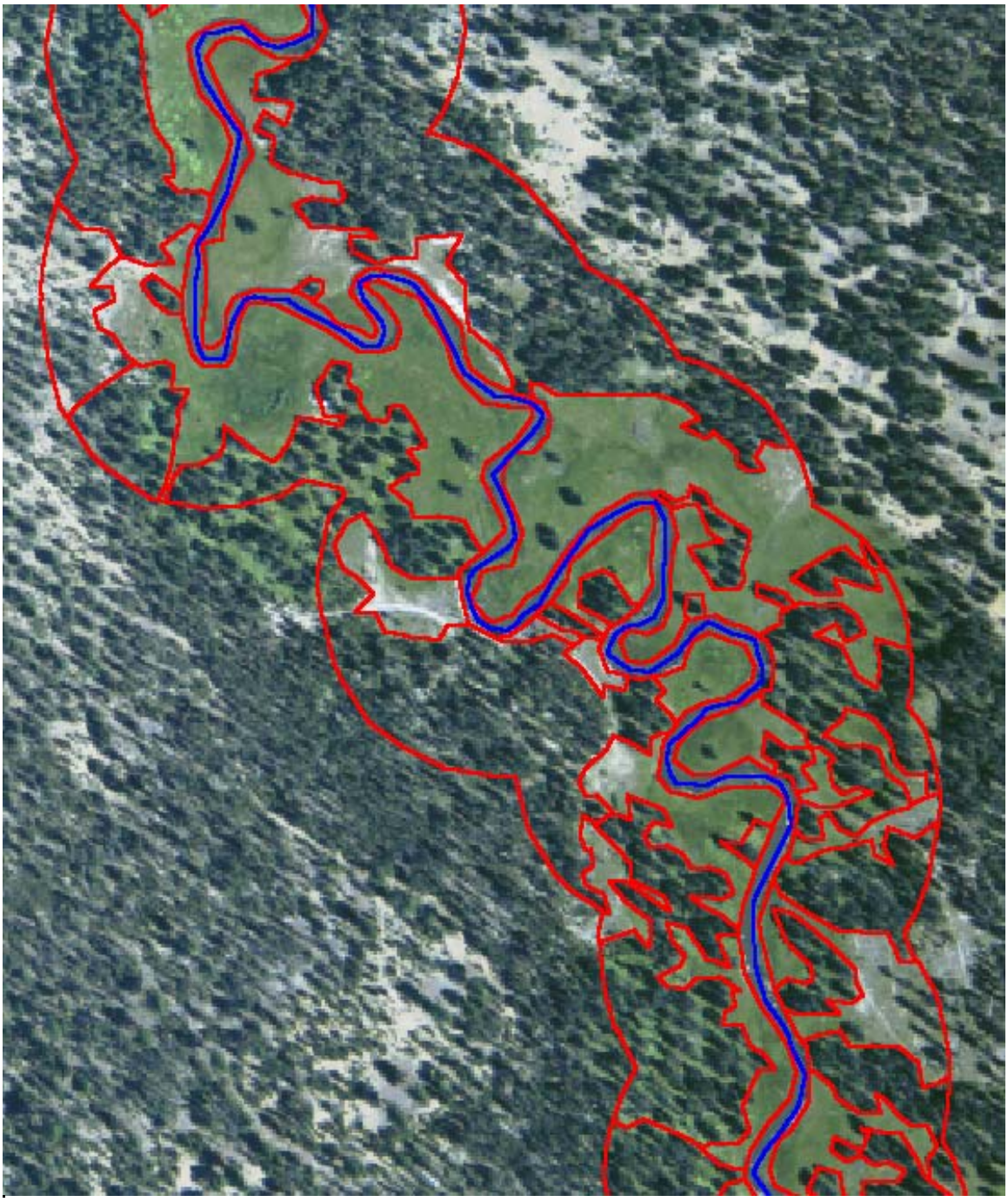


Figure 3-1. *Rectified aerial photo with digitized stream position (blue) and near stream vegetation (red) to 300 feet from channel edge on both banks.*

Terms Used in this Chapter

Accuracy - the degree to which information on a map or in a digital database matches true or accepted values. Accuracy is an issue pertaining to the quality of data and the number of errors contained in a data set or map. In discussing a GIS database, it is possible to consider horizontal and vertical accuracy with respect to geographic position, as well as attribute, conceptual, and logical accuracy.

Automated Sampling – Attributes of spatial data sets are sampled with ODEQ software and placed in a database.

Bankfull Width: The channel width (perpendicular to the channel) at the bankfull height (Rosgen, 1996). "Bankfull is taken to refer to the elevation of the active (i.e. frequently inundated) floodplain immediately adjacent to many stream channels, formed in the current climate regime" (Bakke et al., 2000). Where a fully developed floodplain is not present bankfull indicators can be used, such as: depositional surfaces, vegetation lines or slope breaks (Bakke et al., 2000). Bankfull channel widths generally increase in the downstream direction and may occur in a step-wise manner as a function of discharge and/or stream type changes at a major confluence.

Digital Elevation Model (DEM) – A digital file consisting of terrain elevations for ground positions at regularly spaced horizontal intervals. Converting hypsographic and hydrographic tagged vector files produces accurate elevation models.

Digitize – Manually drawing polylines or polygons around features that are visible in rectified in aerial photography. Spatial data sets for land cover, stream position, channel width, etc. can be developed by digitizing these physical attributes.

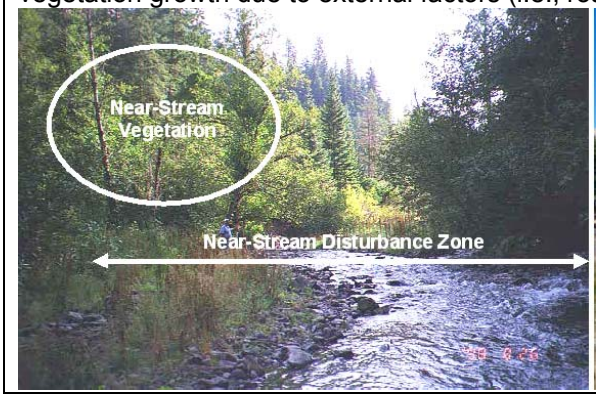
Drainage Area: The upslope area that contributes to flow accumulations above a particular point along a stream. This area is calculated by DEQ at various sites based on hydrography. GridBug, an automated avenue script sampling tool developed by DEQ staff, delineates drainage area using a 30-meter pixel digital elevation model (DEM) as a base layer (Bernert, unpublished 2000).

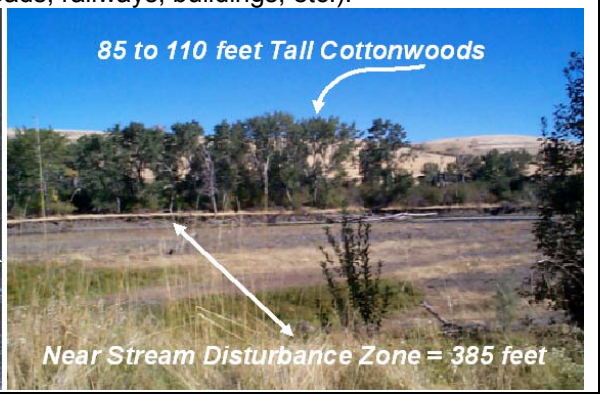
Gradient – Refers to slope and quantified as rise divided by run.

Landsat Data – Satellite data that can be classified to identify landscape features such as vegetation, roads, buildings, etc.

Mass Balance – A longitudinal profile of flow volume derived by accounting for gains and losses of flow.

Near-Stream Disturbance Zone (NSDZ) - is defined for purposes of the TMDL as the width between shade-producing near-stream vegetation. This dimension was measured from rectified digital aerial photography. Where near-stream vegetation was absent, the near-stream boundary was used, defined as downcut stream banks or where the near-stream zone is unsuitable for vegetation growth due to external factors (i.e., roads, railways, buildings, etc.).





Orthophoto – Aerial photos that have been rectified

Plan View – Looking directly down at the earth surface.

Precision - the level of measurement and exactness of description in a GIS database. Precise locational data may measure position to a fraction of a unit. Precise attribute information may specify the characteristics of features in great detail. It is important to realize, however, that precise data--no matter how carefully measured--may be inaccurate. Surveyors may make mistakes or data may be entered into the database incorrectly.

Rectification – Adjusting for distortions caused by terrain elevation gradients and camera angle to produce map quality photo images.

Regional Curve: Leopold et al. (1964) demonstrated that bankfull channel dimensions tend to increase with increases in drainage area. A power function is commonly used to relate channel dimensions to drainage area plotted on a log-log scale. Regional curves are generally constructed for hydrologic units (i.e. stratified by 5^{th}, 4^{th} or 3^{rd} field HUC codes). Rosgen (1996) recommends an additional stratification by a common stream type for regional curves. "When stratified by stream type, plots of bankfull dimensions prove even more useful for estimating similar channel dimensions for ungaged areas" (Rosgen, 1996). Level I Rosgen channel types are used to stratify the regional curves presented below.

Resolution – Scale for which a spatial data set is accurate

Sinuosity – A quantification of the degree of meander in a stream segment.

Stream Data Node – The points created along the stream centerline at a 100-foot interval used to sample topographic, channel and land cover parameters.

Width to Depth Ratio - Bankfull width divided by bankfull depth.

3.1 Sampled Parameters

Sampling numeric GIS data sets for several landscape parameters and performing simple calculations is done to derive spatial data for several stream parameters. Sampling density is user-defined and generally matches any GIS data resolution and accuracy. The sampled parameters used in the stream temperature analysis are:

- Stream Position and Aspect,
- Stream Elevation and Gradient (stream bed, valley - transverse and longitudinal),
- Maximum Topographic Shade Angles (East, South, West),
- Channel Width,
- FLIR Temperature Data Associations, and
- Near Stream Land Cover.

The following sections of this chapter detail the methodologies, results, resolution and accuracy for each derived data type.

3.2 Resolution - Map Scale & Horizontal Accuracy

Development and refinement of spatial data focuses on achieving the highest resolution (i.e., less than 1:5,000). This includes digitizing high-resolution aerial imagery and checking against ground level data. In many cases land cover can be accurately mapped from existing and publicly available digital orthophotos. Streams and channel edges can also be quickly and accurately mapped to less than 1:5,000 from orthophotos, provided that channel edges are visible in plan view and are several times greater than the photo resolution. In both cases ground level data are used to assess spatial data accuracy.

Ground features are accurate within the limits of the mapping accuracy. Landscape parameters can only be reliably measured when considering the accuracy limitations. Oregon DEQ recommends GIS data mapping scales that target 1:5,000 or less, with the exception of DEMs, where 10-meter pixel data are preferred.

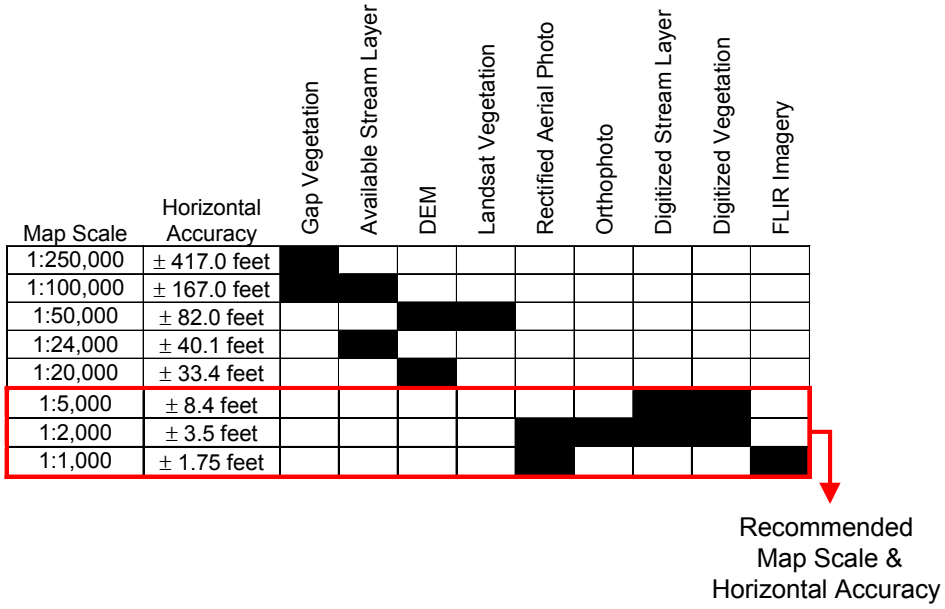


***Figure 3-2**. Accuracy Limitations for Different Map Scales*

When sampling spatial data sets it is important to consider the accuracy of the GIS data being sampled. Many data sources/types are available (Stream Layers, Digital Elevation Models, Vegetation Data, etc.); however, much of this data is coarse and may fail to capture spatially variable landscape parameters. Whenever possible ODEQ samples at a high resolution. However, sampling resolution should not exceed the accuracy of the data being sampled.

Stream position is used to develop reference points for sampling. The stream polyline accuracy is a function of the map scale. For example, **Figure 3-3** demonstrates that a stream polyline at 1:100,000 mapping scale (red line) simplifies sinuosity and has local horizontal inaccuracies of over 200 feet. Sampling with a 1:100,000 stream polyline will result in inaccurate sampling reference points and simplified stream sinuosity. As can be seen in **Figure 3-3**, a stream polyline digitized at 1:5,000 mapping scale will properly identify stream position and will yield accurate spatial reference points for sampling of other stream parameters relative to the stream data node.

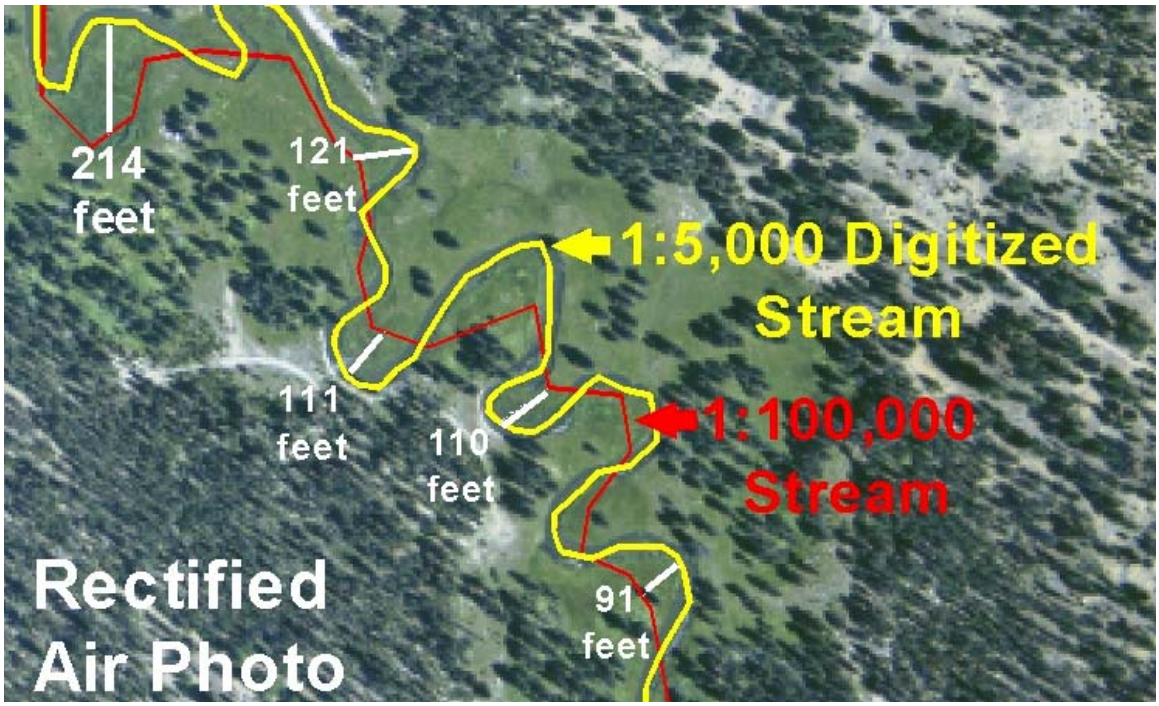


***Figure 3-3**. Map Scales Comparing Stream Polyline Accuracy at 1:100,000 and 1:5,000*

3.3 Stream Mapping and Segment Data Nodes

Stream position is mapped at 1:5,000 or less using rectified aerial photos and digital orthophoto quads. The centerline of the stream is estimated and digitized as a continuous stream polyline. Where the stream channel is braided, the largest stream channel is digitized. This stream polyline is then segmented into point data nodes at 100-foot intervals. Oregon DEQ has found that a 100-foot longitudinal sampling interval maintains data resolution without creating data sets that overwhelm hardware limitations (i.e., computer memory and CPU time). The resulting segmented point data nodes are used for sampling of the derived data parameters.

3.4 Channel Morphology

3.4.1 Overview

Channel morphology is largely a function of high flow volume magnitude and frequency, stream gradient, sediment supply and transportation, stream bed and bank materials and stream bank stability (Rosgen 1996 and Leopold et al. 1964).

Ground level measured and GIS sampled channel morphology data reveals that some stream reaches in the Upper Klamath Lake drainage have experienced channel widening. These stream reaches were identified by developing regional curves for bankfull width estimates as a function of drainage area. Degraded channel morphology largely results from channelization and/or near stream vegetation disturbance. Due to lack of data the impact of sedimentation on channel morphology is not quantified, however, the typical response is channel widening, amongst other channel responses.

The predominant thermodynamic influence of channel morphology is quite simple. Wider channels result in the combined effect of increased solar radiation loading via decreased stream surface shade and increased stream surface area exposed to solar radiation loading. A wider stream has a larger surface exposed to surface thermal processes. Other thermal effects that relate to channel morphology include altered stream hydraulics caused by increased wetted perimeter and decreased stream depth. Disturbance of surface and groundwater interactions may also result from channel morphology modifications and have the combined effects of lowering near stream groundwater tables, reducing the groundwater inflow, removing cool sources of groundwater that serve to reduce instream temperatures and modifying hyporheic flows. Substrate changes may decrease or impair hyporheic flows (i.e. flows that occur in the interstitial spaces in the bed substrate) that help buffer stream temperature change.

Passive restoration of channel morphology should be a primary focus of temperature related restoration efforts in the Upper Klamath Lake drainage. Passive restoration efforts should include: removing sources of channel disturbance that are known to degrade and slow or prevent restoration. Near stream land cover is a primary component in shaping channel form and function and should be a significant emphasis in all restoration planning and activities. Active restoration should be considered where severe channel disturbances cannot be remedied via passive restoration techniques. Examples of areas where active restoration should be considered should include severe vertical down cutting, diked channels and removal of instream structures that prevent progress towards the desired stream channel condition. Other instream structures can serve as beneficial in channel restoration such as rock barbs, sediment catchments, etc.

3.4.2 Assessment Methodology

The derived channel morphology data types are described in detail in this section. GIS data sampling is performed with Ttools[12]. Derived data sets that relate to channel morphology are developed for the following streams and rivers in the Upper Klamath Lake drainage:

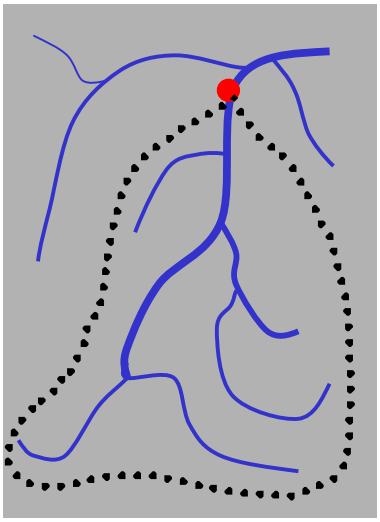
- Williamson River
- North Fork Sprague River
- South Fork Sprague River
- Trout Creek
- Sprague River
- Sycan River
- Fishhole Creek

[12] Ttools is a sampling extension developed for ArcView. It is used by Oregon DEQ to create spatial data sets for stream networks. DEQ currently maintains the Ttools methodology and computer programming. Ttools and supporting documentation can be downloading from Deq at: http://waterquality.deq.state.or.us/wq/TMDLs/WQAnalTools.htm.

Drainage Area

Drainage area is delineated and measured from a 30-meter digital elevation model (DEM). A sampling tool developed by ODEQ delineates the contributing area of the watershed above specified locations along a stream. Surface area within the delineation is calculated in 30-meter pixel units. The stream data nodes are the points of reference for sampling.

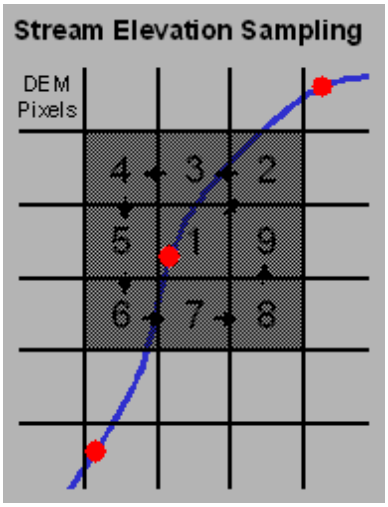
Drainage area data are used for regional curve development.



Stream Elevation

Stream elevation is measured from a 10-meter digital elevation model (DEM). Ttools[5] will auto-detect the pixel size (either 10 meter or 30 meter) of the DEM. In order to find the lowest pixel nearest to the stream segment node, TTools samples nine pixels: the pixel that falls directly on the stream segment node and the eight surrounding pixels. The lowest elevation sampled is assigned to the stream segment node.

Stream elevation data are used to calculate stream gradients.



Stream Gradient

Stream gradient is calculated from the elevation of the stream node and the distance between nodes. The DEMs have a 3.3 feet (one meter) elevation resolution. It commonly occurs that a measurable (i.e. greater than 3.3 feet) elevation drop spans several of the stream segment nodes. Gradients are calculated as:

$$\text{Stream Gradient} = \frac{\text{Change in Stream Elevation}}{\text{Stream Segment Length}} = \frac{\text{Change in Stream Elevation}}{(\text{\# of Stream Nodes})(\text{Segment Interval})}$$

Stream gradient data are used to:

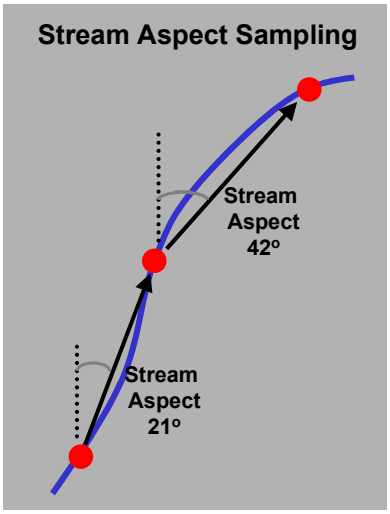
- *Calculate stream velocity with Mannings equation*
- *Classify Rosgen level I stream types.*

Stream Aspect

Stream aspect is calculated as the downstream angle between two stream nodes and north. Units recorded are degrees from north, in the downstream direction.

Stream aspect data are used to:

- *Reference the longitudinal direction and allows the calculation of the transverse direction at each stream data node,*
- *Position the stream relative to simulated surrounding features such as the sun, surrounding near stream land cover and shade producing topographic features.*

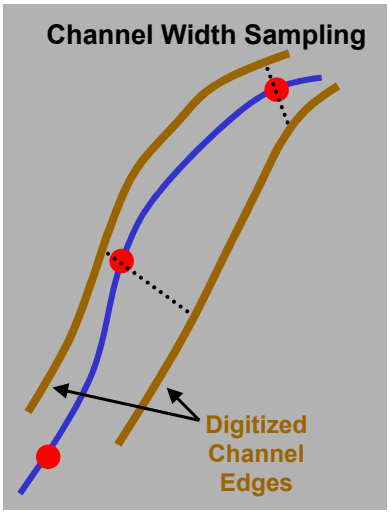


Near Stream Disturbance Zone Width

Near stream disturbance zone width can be measured from digitized channel edge polylines. At each stream segment node, TTools measures the distance between the left and right channel edge polylines in the transverse direction (i.e., perpendicular to the aspect).

Near stream disturbance zone width data are used to:

- *Approximate bankfull width,*
- *Serve as inner boundaries where transverse near stream land cover sampling starts.*



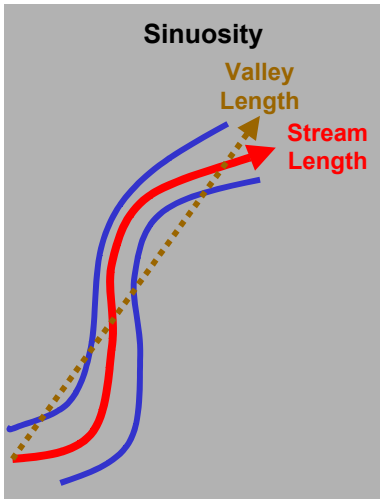
Stream Sinuosity

Stream sinuosity is the stream length to valley length ratio. Sinuosity data are calculated as:

$$\text{Stream Sinuosity} = \frac{\text{Stream Length}}{\text{Valley Length}}$$

Stream sinuosity data are used to:

- *Assess stream condition,*
- *Develop Rosgen level I channel classifications.*



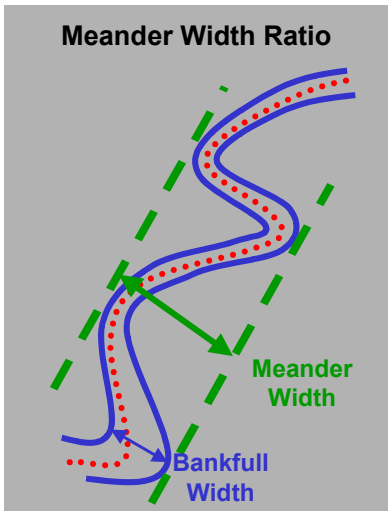
Meander Width Ratio

Meander width ratio is the meander width to bankfull width ratio. Meander width is the belt width or amplitude of the meander geometry.

$$\text{Meander Width Ratio} = \frac{\text{Meander Width}}{\text{Bankfull Width}}$$

Meander width ratio data are used to:

- *Assess stream condition,*
- *Develop Rosgen level I channel classifications*



3.4.3 Stream Gradient, Sinuosity, and Meander Width Ratio

GIS derived stream gradient, sinuosity and meander width ratio data are used to assess stream condition and help classify Rosgen level I stream types. Additional data used to develop stream types are USFS ground level stream classifications. In some cases the Rosgen data ranges are quite broad and staff professional judgements were used to type streams. In general, Rosgen level I stream types can be described as follows:

Type A - High Relief, Erosional/Depositional and Bedrock Features, Entrenched and Confined Streams w/ Cascading Reaches

Type B - Moderate Relief, Moderate Entrenchment and W/D Ratio, Narrow Gently Sloping Valleys, Rapids Predominate w/ Scour Pools

Type C - Broad Valleys w/ Terraces, Associated w/ Floodplains, Alluvial Soils Slightly Entrenched, Well Defined Meandering Channels

Type D - Broad Valleys w/ Alluvium, Steeper Fans, Glacial Debris, Active Lateral Adjustment, Abundant Sediment Supply, Aggradational Processes, High Bedload and Bank Erosion

Type DA - Broad Low Gradient Valleys, Fine Alluvium, Multiple Channels, Laterally Stable w/ Broad Wetland Floodplains, Very Low Bedload, High Wash Load Sediment

Type E - Broad Valley/Meadows, Alluvial Materials w/ Floodplains, Highly Sinuous, Stable Well Vegetated Banks, Very Low W/D

Type F - Entrenched in Highly Weathered Material, Gentle Gradients, High W/D, Meandering Laterally, Unstable w/ High Bank Erosion Rates

Type G - Gullies, Moderate Slopes, Low W/D Ratio, Narrow Valleys or Deeply Incised, Unstable, High Bank Erosion

Table 3-1. Channel Gradient, Sinuosity, Meander Width Ratios and Rosgen Stream Types
(Data from Rosgen, 1996)

Channel	Channel Gradient	Sinuosity	Width to Depth Ratio	Meander Width Ratio	Entrenchment Ratio	Rosgen Channel Type
Single	**High** Ave = 15.7% (5% - 47%)	**Low** Ave = 1.07 (1.0 - 1.4)	**Low** Ave = 7.9 (3 - 12)	**Low** Ave = 1.5 (1 - 3)	**Low** Ave = 1.24 (1.0 - 1.4)	**Type A**
	Moderate Ave = 3.0% (0.2% - 10%)	**Low** Ave = 1.33 (1.1 - 1.7)	**Moderate** Ave = 18.6 (11 - 39)	**Low** Ave = 3.7 (2 - 8)	**Low** Ave = 1.59 (1.2 - 2.2)	**Type B**
	Low Ave = 0.29% (0.02% - 1.3%)	**Very High** Ave = 2.26 (1.2 - 4.0)	**High** Ave = 29.8 (10 - 90)	**High** Ave = 11.4 (4 - 20)	**High** Ave = 3.71 (2.3 - 32.2)	**Type C**
	Moderate Ave = 1.63% (0.02% - 5.8%)	**Very High** Ave = 2.01 (1.2 – 3.1)	**Low** Ave = 7.1 (2 - 12)	**Very High** Ave = 24.2 (20 - 40)	**High** Ave = 41.13 (2.5 - ∞)	**Type E**
	Low Ave = 0.45% (0.01% - 2.4%)	**Moderate** Ave = 1.56 (1.4 - 2.0)	**High** Ave = 27.6 (12 - 95)	**Moderate** Ave = 5.3 (2 - 10)	**Low** Ave = 1.15 (1.0 - 1.4)	**Type F**
	Moderate Ave = 1.97% (0.03% - 3.9%)	**Low** Ave = 1.36 (1.2 - 1.6)	**Low** Ave = 8.0 (3 - 11)	**Low** Ave = 3.7 (2 - 8)	**Low** Ave = 1.22 (1.1 - 1.4)	**Type G**
Multiple	**Low** (< 4%)	Variable	n/a	**Low** Ave = 1.1 (1 - 2)	n/a	**Type D**
	Very Low (< 0.5%)	Variable	n/a	n/a	n/a	**Type DA**

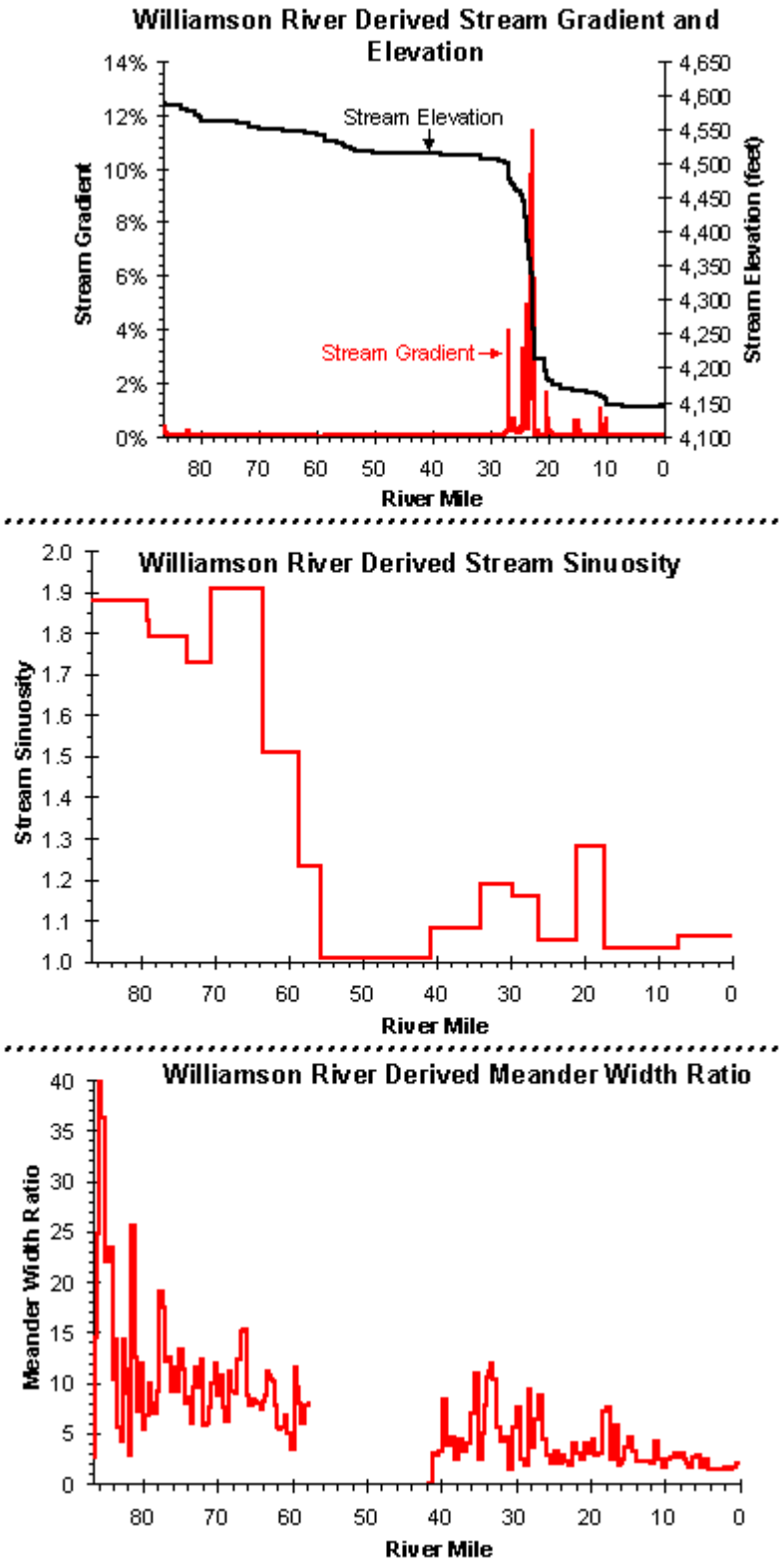


***Figure 3-4**. Williamson River - Stream Gradient, Sinuosity and Meander Width Ratio*

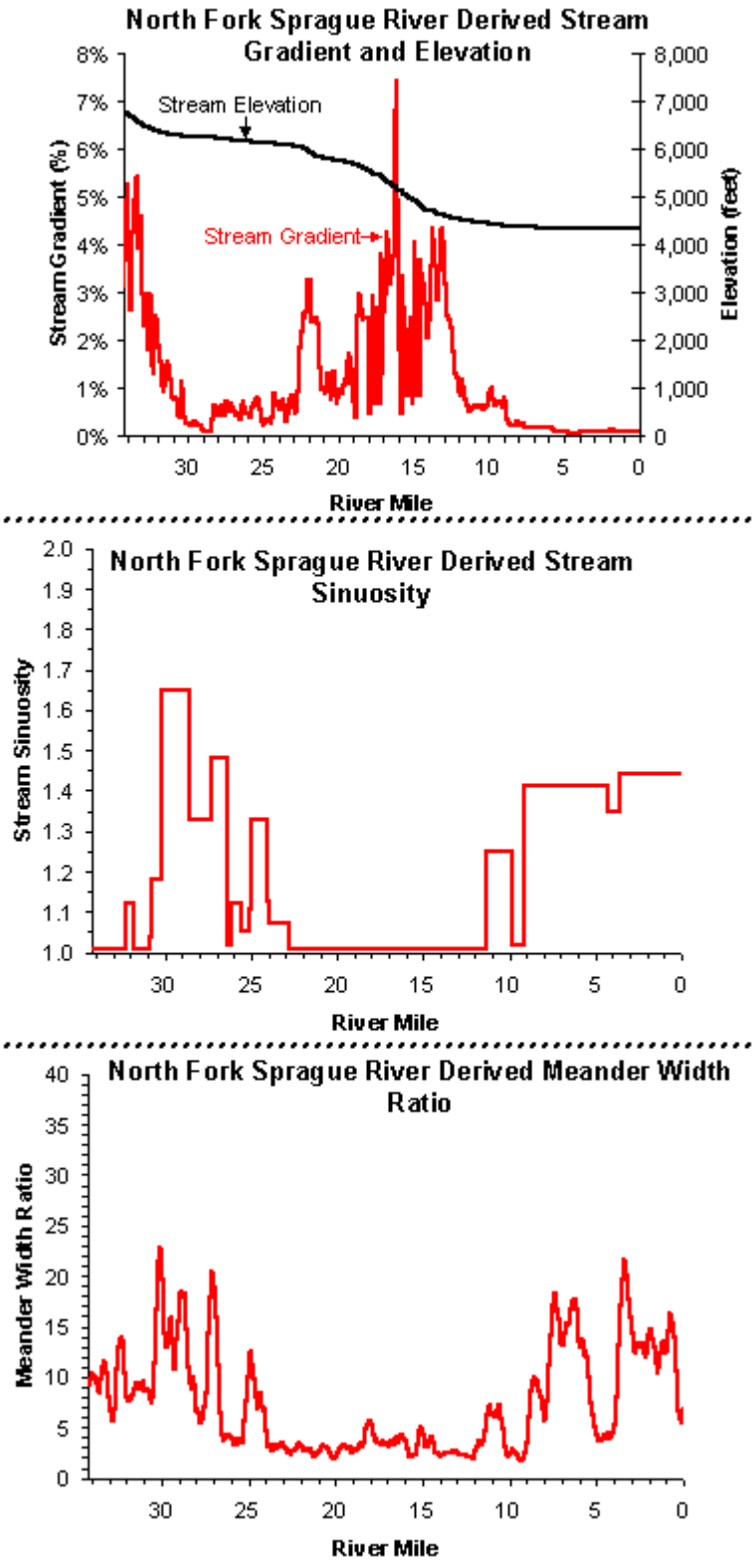


Figure 3-5. *North Fork Sprague River - Stream Gradient, Sinuosity and Meander Width Ratio*

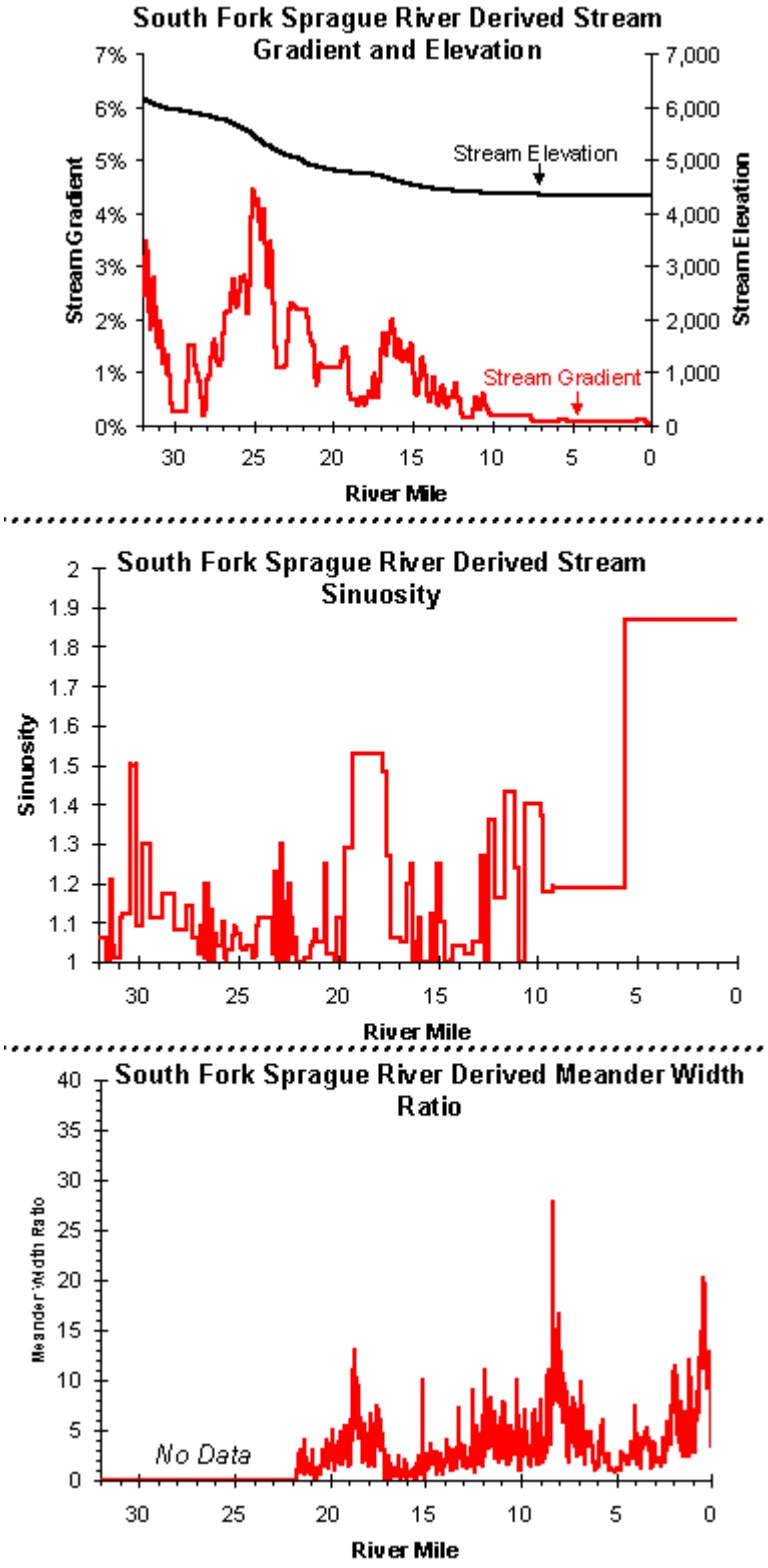


***Figure 3-6**. South Fork Sprague River - Stream Gradient, Sinuosity and Meander Width Ratio*

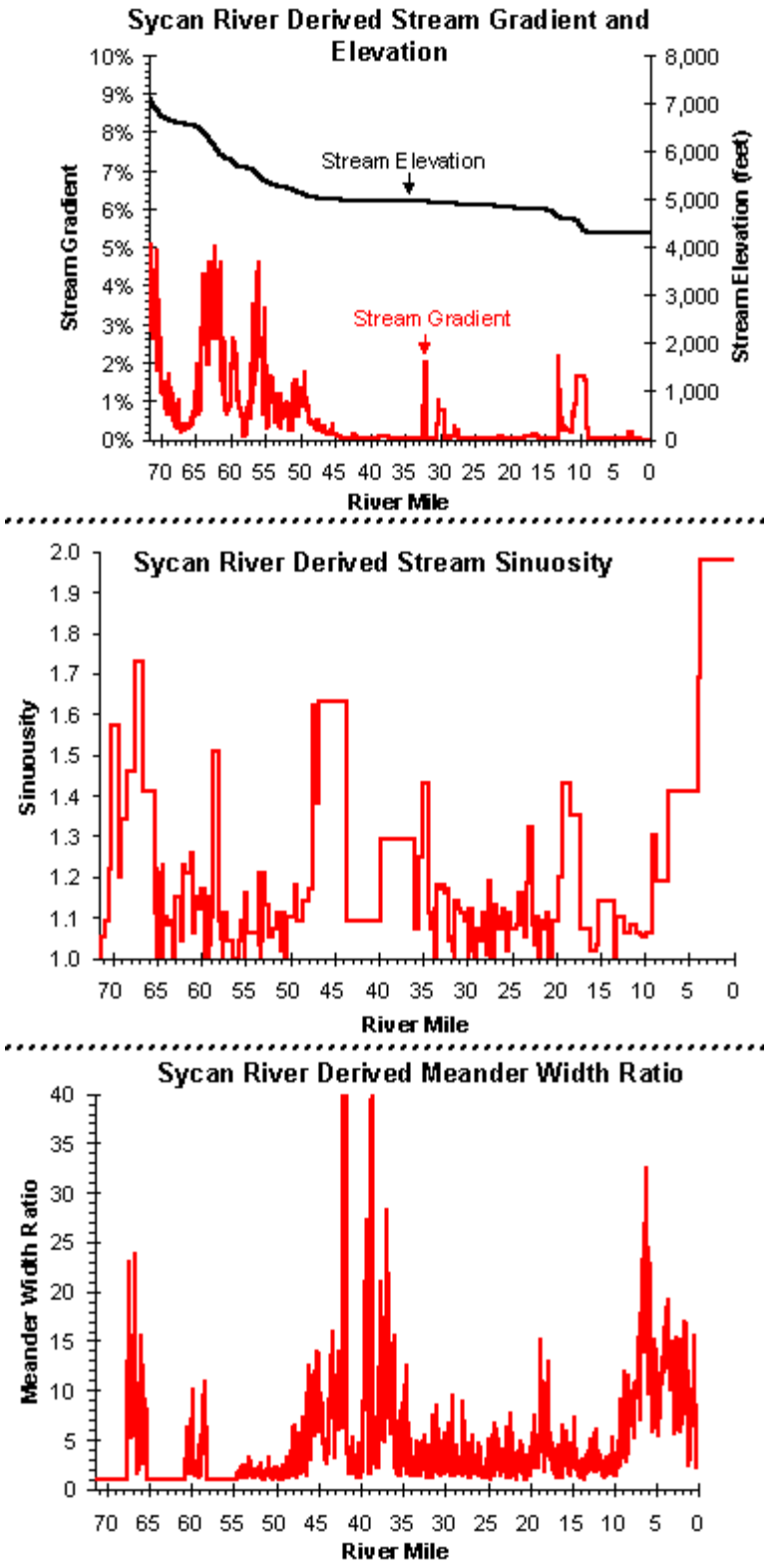


***Figure 3-7**. Sycan River - Stream Gradient, Sinuosity and Meander Width Ratio*

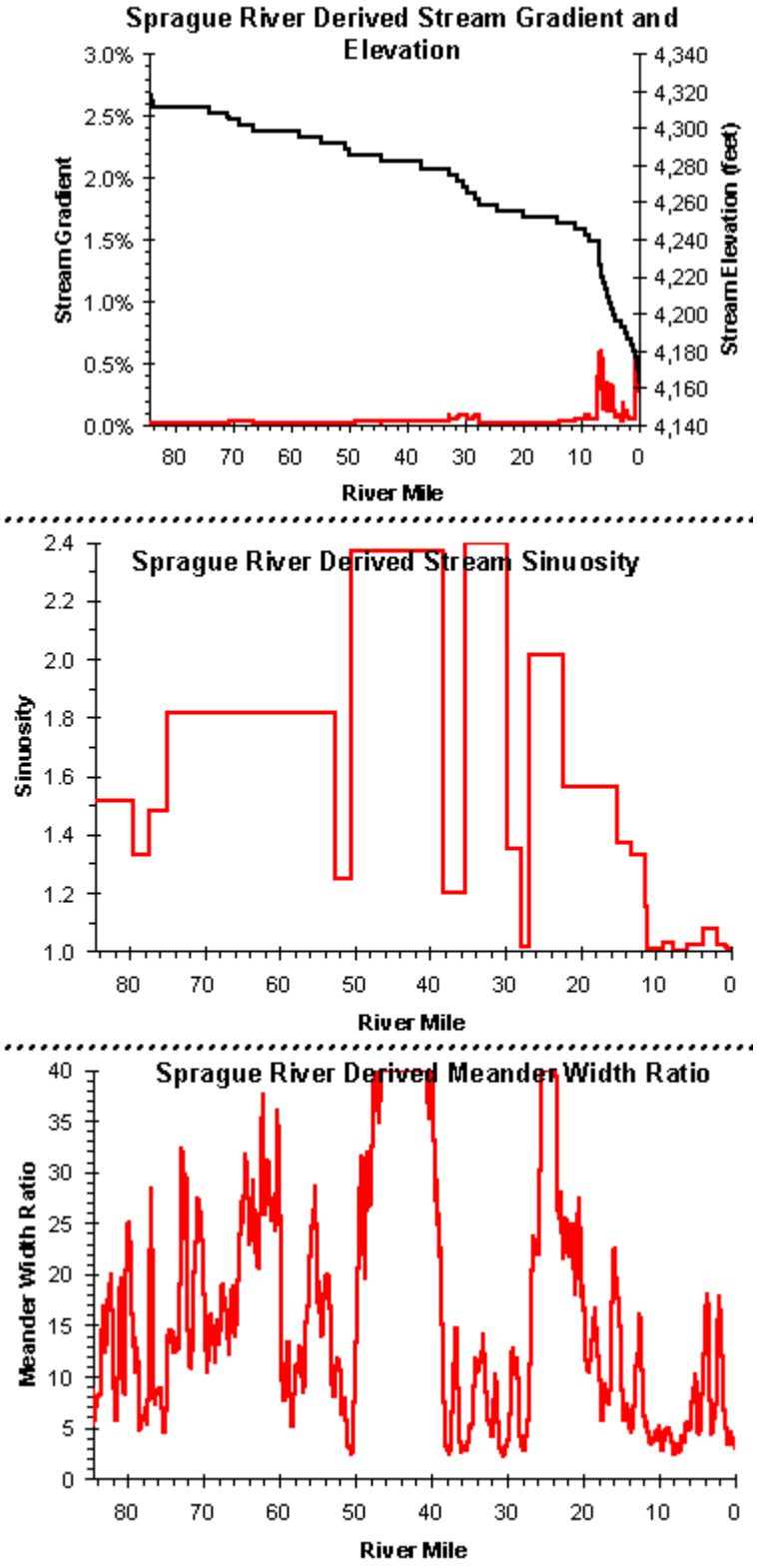


Figure 3-8. *Sprague River - Stream Gradient, Sinuosity and Meander Width Ratio*

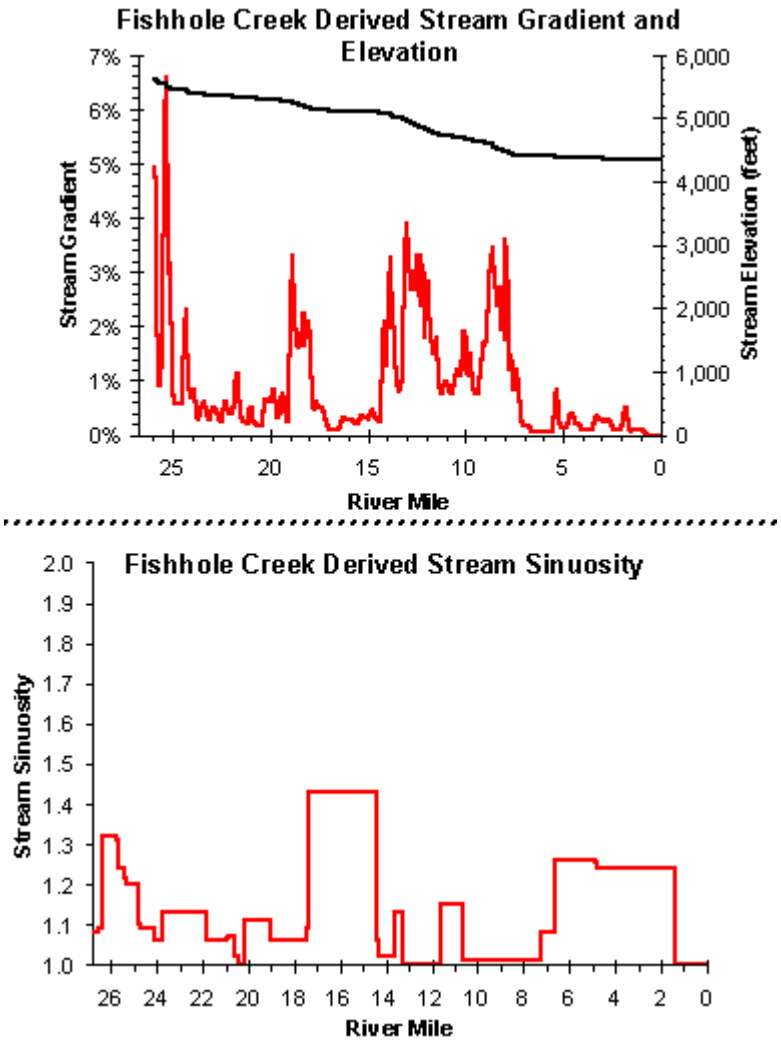


Figure 3-9. *Fishhole Creek - Stream Gradient and Sinuosity*

3.4.4 Channel Width Assessment

Channel width is an important component in stream heat transfer and mass transfer processes. Effective shade, stream surface area, wetted perimeter, stream depth and stream hydraulics are all highly sensitive to channel width. Accurate measurement of channel width across the stream network, coupled with other derived data, allows a comprehensive analytical methodology for assessing channel morphology. The step for channel width assessment are listed below and displayed in the graphics that follow.

Step 1. **Stream channel edges are digitized from rectified digital aerial photography at 1:5,000 or less**. These channel boundaries establish the near stream disturbance zone, which is defined for purposes of the TMDL, as the width between shade-producing near-stream vegetation. Where near-stream vegetation is absent, the near-stream boundary is used, defined as downcut stream banks or where the near-stream zone is unsuitable for vegetation growth due to external factors (i.e., roads, railways, buildings, etc.).

Step 2. **Sample near stream disturbance zone width at each stream data node using Ttools**. The sampling algorithm measures the near stream disturbance zone width in the transverse direction relative to the stream aspect.

Step 3. **Assess the accuracy of sampled near stream disturbance zone width in estimating ground level bankfull width measurements**. Establish statistical limitations for near stream disturbance zone width values when used for estimating bankfull width.

Step 4. **Relate bankfull discharge to drainage area**. Bakke et al. (2000) presents regional curves developed for Klamath Basin and surrounding area stream systems that relate bankfull discharge to drainage area. Two relationships are developed based on drainage area magnitude: less than 100 mi^2 and greater than 100 mi^2.

Step 5. **Relate bankfull cross-sectional area to bankfull discharge.** Bakke et al. (2000) also presents a regional curve relationship for bankfull channel cross-sectional area and drainage area that is valid for drainage areas less than 100 mi^2 (260 km^2). While this relationship proves useful is assessing small order streams, it becomes limited since it applies to those with small drainage areas. In attempt to extend the relationship between bankfull channel cross-sectional area and drainage area, DEQ has developed a relationship between bankfull channel cross-sectional area and bankfull discharge. This relationship is based on the Bakke et al. (2000) relationship for bankfull discharge and drainage area less than 100 mi^2 (260 km^2).

Step 6. **Relate bankfull cross-sectional area to drainage area.** Substituting the Bakke et al. (2000) regional curve relationships for bankfull discharge into the DEQ derived relationship for bankfull cross-sectional area and bankfull discharge allows bankfull cross-sectional area to be expressed as a function for all drainage areas. The two bankfull discharge regional curve relationships presented by Bakke et al. (2000) produce two relationships for bankfull cross-sectional area: less than (100 mi^2) 260 km^2 and greater than (193 mi^2) 500 km^2. The area between the two curves is simply the highest value of the less than 260 km^2 relationship extended to the greater than 500 km^2 relationship. Since the two relationships predict different values for the 260 km^2 to 500 km^2 region of the curve, the higher values are used.

Step 7. **Methodology Overview**

Step 8. **Validate Methodology** - It should be noted that validation of the DEQ derived curve for drainage areas greater than 500 km^2 is not possible due to lack of data. There is an implicit assumption that the relationship between bankfull discharge and bankfull cross-sectional area is valid throughout the range of drainage areas analyzed by this approach (0 to 10,000 km^2).

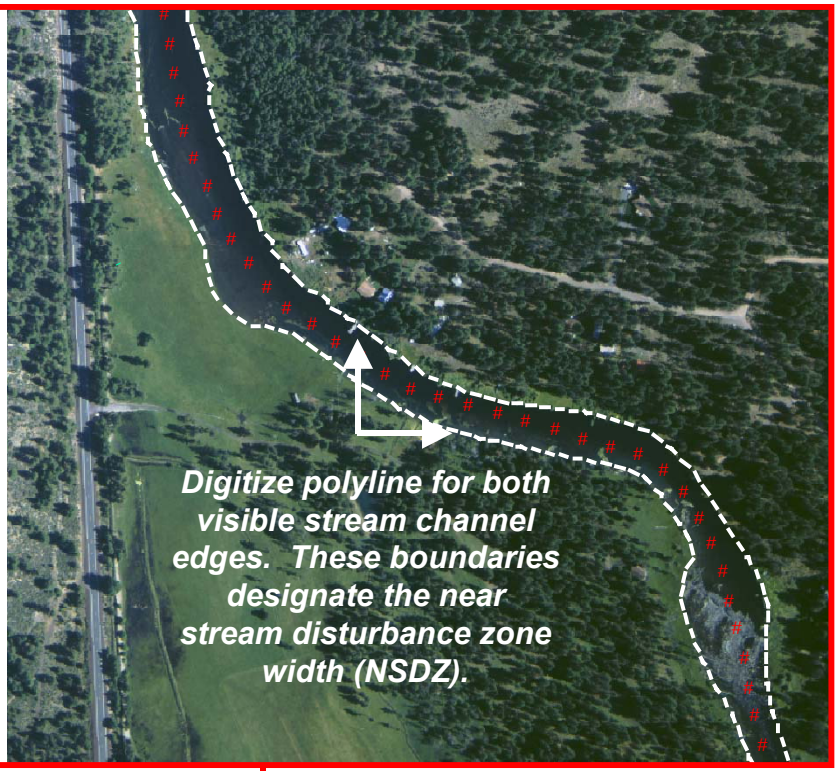
Step 9. **Relate Bankfull Width Values to Stream Type, Width to Depth and Drainage Area.** Bankfull width can be estimated as a function of width to depth ratio and cross-sectional area. Using this relationship for bankfull width, it is possible to relate bankfull width to drainage area and width to depth ratios. This relationship is used for a best fit to measured NSDZ width data. Drainage areas for all stream data nodes are calculated from 30-meter digital elevation model data. Width to depth ratios are the variable used as the basis for the best fit relationship. All derived width to depth ratios are within published ranges for level I stream types (Rosgen, 1996).

Step 10. **Potential bankfull width is developed as a function of stream type, drainage area and width to depth ratios**. Using the regional curve relationships for bankfull width as a threshold condition, departures from this threshold become evident. Potential bankfull widths are assumed to be those that are at or below the regional curve threshold for the appropriate stream type.

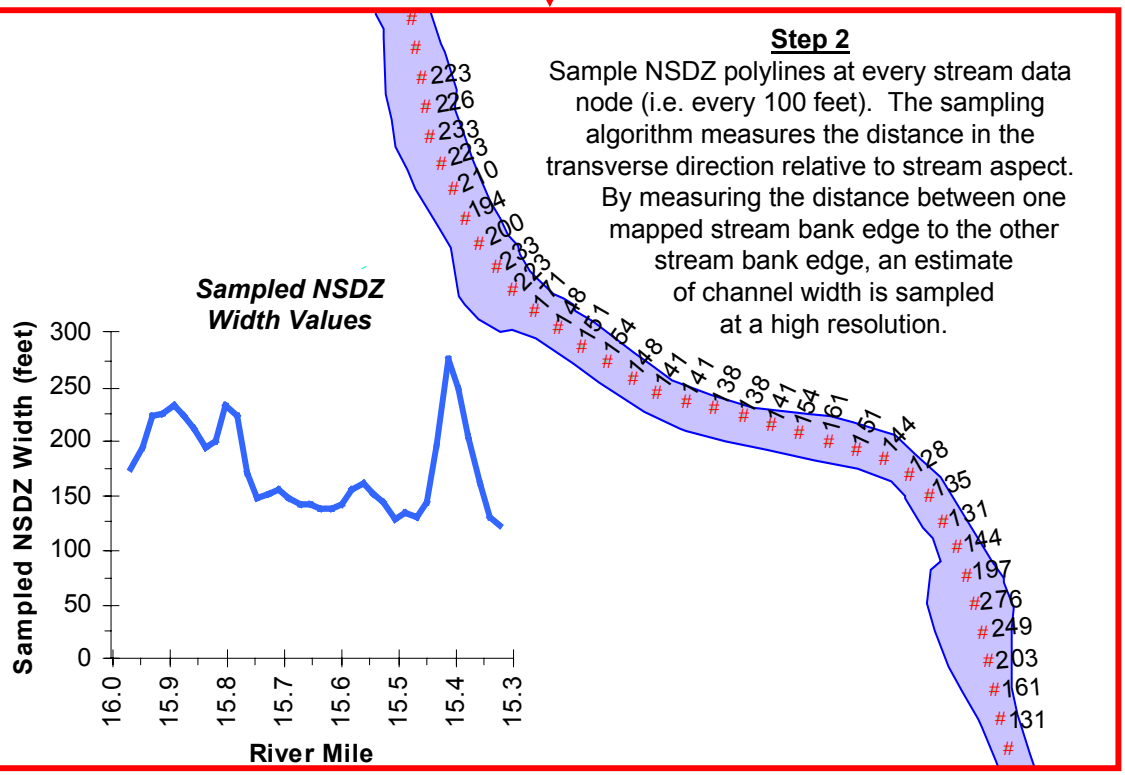
Channel Width Assessment

Step 1
Digitize Channel Edge Polylines at 1:5,000

ODEQ refers to these stream edge boundaries as the near stream disturbance zone width (NSDZ).



Step 2
Sample NSDZ polylines at every stream data node (i.e. every 100 feet). The sampling algorithm measures the distance in the transverse direction relative to stream aspect. By measuring the distance between one mapped stream bank edge to the other stream bank edge, an estimate of channel width is sampled at a high resolution.



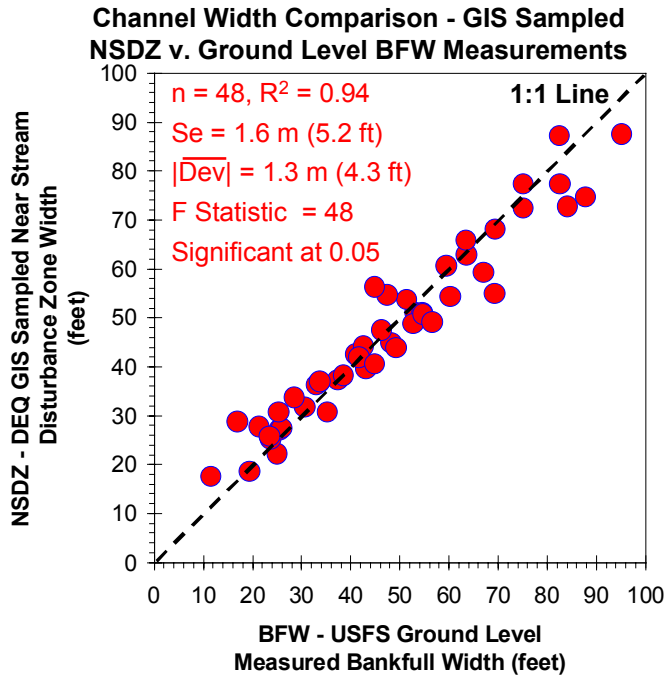
Channel Width Assessment

Step 3

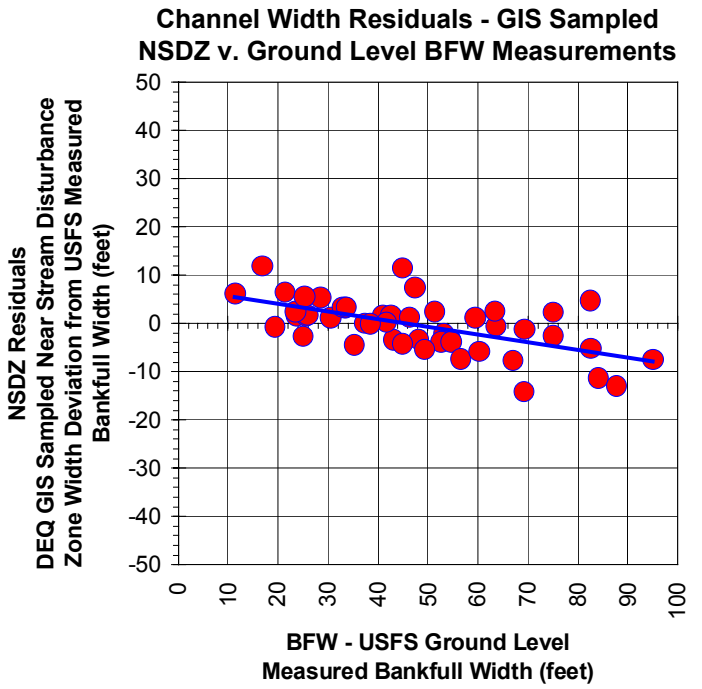
Assess accuracy of ODEQ NSDZ width sampled data compared to USFS bankfull width ground level measurements.

In general, the NSDZ width serves as an accurate estimate of bankfull widths. When compared to ground level bank full width data, NSDZ width samples have a correlation coefficient of 0.94, a standard error or 5.2 feet and an average absolute deviation of 4.3 feet.

NSDZ width samples can be used to estimate bankfull width provided that statistical accuracy limitations are acknowledged.



This methodology may over estimate bankfull widths for narrow stream channels and under estimate bankfull channel width for wider stream channels. Sources of error include limited by aerial photo resolution, plan view line of sight to the stream channel boundaries and the clarity of the channel edge (i.e. there must be a visibly defined channel boundary). There is an obvious bias to the methodology towards features visible in plan view. Vertical features (i.e. channel incisions, cut banks, flood plain relief, etc.) can be difficult to distinguish for aerial photos.



Channel Width Assessment

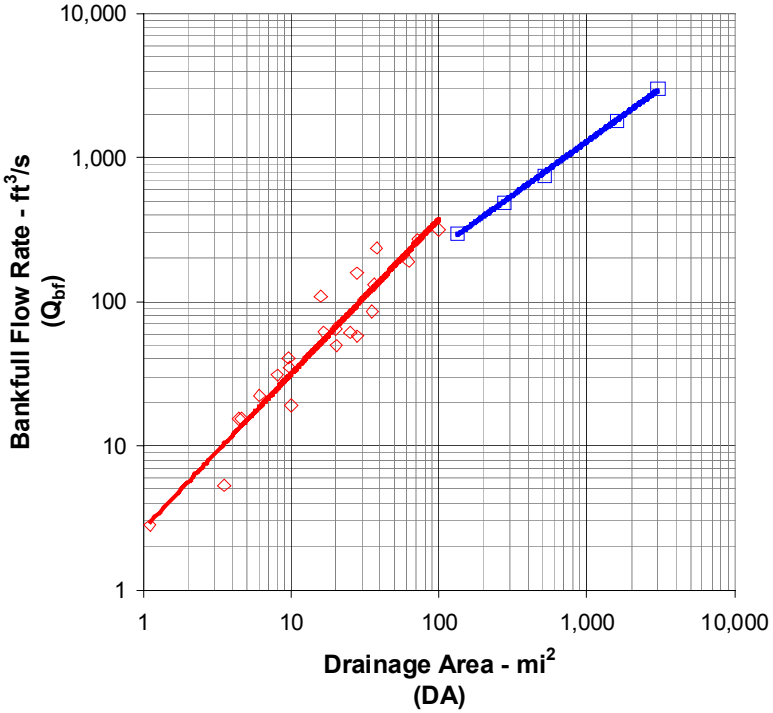
Step 4
Relate bankfull discharge to drainage area

Bakke et al. (2000) presents regional curves developed for Klamath Basin and surrounding area stream systems that relate bankfull discharge to drainage area. Two relationships are developed based on drainage area magnitude: less than 100 mi^2 and greater than 100 mi^2.

Metric Units	*English Units*
A_{bf}: Bankfull Cross-Sectional Area (m^2) DA: Drainage Area (km^2) Q_{bf}: Bankfull Discharge (m^3/s)	A_{bf}: Bankfull Cross-Sectional Area (ft^2) DA: Drainage Area (mi^2) Q_{bf}: Bankfull Discharge (ft^3/s)
Bankfull Discharge as a Function of Drainage Area, For all DA < 260 km^2 $Q_{bf} = 0.0272 \cdot DA^{1.0740}$ ($R^2 = 0.91$) For all DA > 260 km^2 $Q_{bf} = 0.1090 \cdot DA^{0.7400}$ ($R^2 > 0.99$) (Bakke et al., 2000)	Bankfull Discharge as a Function of Drainage Area, For all DA < 100 mi^2 $Q_{bf} = 2.6694 \cdot DA^{1.0740}$ ($R^2 = 0.91$) For all DA > 100 mi^2 $Q_{bf} = 7.7843 \cdot DA^{0.7400}$ ($R^2 > 0.99$) (DEQ analysis)

Bankfull Discharge v. Drainage Area

Regional curves for bankfull discharge and drainage area – Klamath Basin and surround area stream systems (data from Bakke et al., 2000).



For DA < 260 km^2 (100 mi^2)

Metric Units

$Q_{bf} = 0.0272 \cdot DA^{1.0740}$

English Units

$Q_{bf} = 2.6694 \cdot DA^{1.0740}$

n = 21, $R^2 = 0.91$

Se = 0.1600 m^3/s (5.65 ft^3/s)

F Statistic = 213

Significant at 0.05

For DA > 260 km^2 (100 mi^2)

Metric Units

$Q_{bf} = 0.1090 \cdot DA^{0.7400}$

English Units

$Q_{bf} = 7.7843 \cdot DA^{0.7400}$

n = 5, $R^2 > 0.99$

Se = 0.0179 m^3/s (0.63 ft^3/s)

F Statistic = 2090

Significant at 0.05

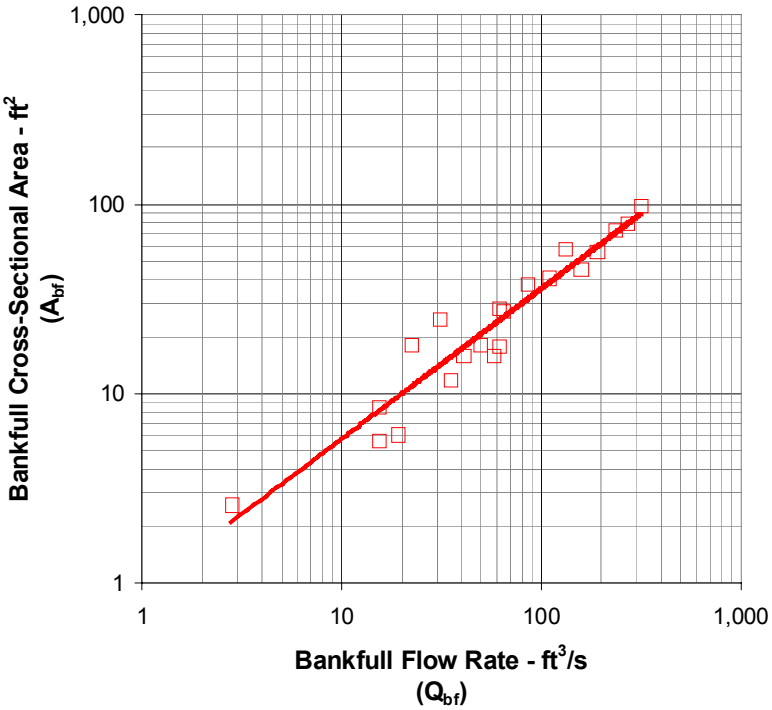
Channel Width Assessment

Step 5
Relate bankfull cross-sectional area to bankfull discharge

Bakke et al. (2000) also presents a regional curve relationship for bankfull channel cross-sectional area and drainage area that is valid for drainage areas less than 100 mi^2 (260 km^2). While this relationship proves useful is assessing small order streams, it becomes limited since it applies to those with small drainage areas. In attempt to extend the relationship between bankfull channel cross-sectional area and drainage area, DEQ has developed a relationship between bankfull channel cross-sectional area and bankfull discharge. This relationship is based on the Bakke et al. (2000) relationship for bankfull discharge and drainage area less than 100 mi^2 (260 km^2).

Metric Units	*English Units*
A_{bf}: Bankfull Cross-Sectional Area (m^2) DA: Drainage Area (km^2) Q_{bf}: Bankfull Discharge (m^3/s)	A_{bf}: Bankfull Cross-Sectional Area (ft^2) DA: Drainage Area (mi^2) Q_{bf}: Bankfull Discharge (ft^3/s)
Bankfull Cross-Sectional Area as a Function of Bankfull Discharge, $A_{bf} = 1.5009 \cdot Q_{bf}^{0.7792}$ (DEQ analysis)	Bankfull Cross-Sectional Area as a Function of Bankfull Discharge, $A_{bf} = 1.0050 \cdot Q_{bf}^{0.7792}$ (DEQ analysis)

Bankfull Cross-Sectional Area v. Bankfull Discharge
Relationship between bankfull cross-sectional area and bankfull discharge – Klamath Basin and surround area stream systems (data from Bakke et al., 2000, DEQ analysis)



For DA < 260 km^2 (100 mi^2)

Metric Units
$A_{bf} = 1.5009 \cdot DA^{0.7792}$

English Units
$A_{bf} = 1.0050 \cdot DA^{0.7792}$

n = 21, R^2 = 0.92
Se = 0.55 m^2 (5.92 ft^2)
F Statistic = 231
Significant at 0.05

Step 6

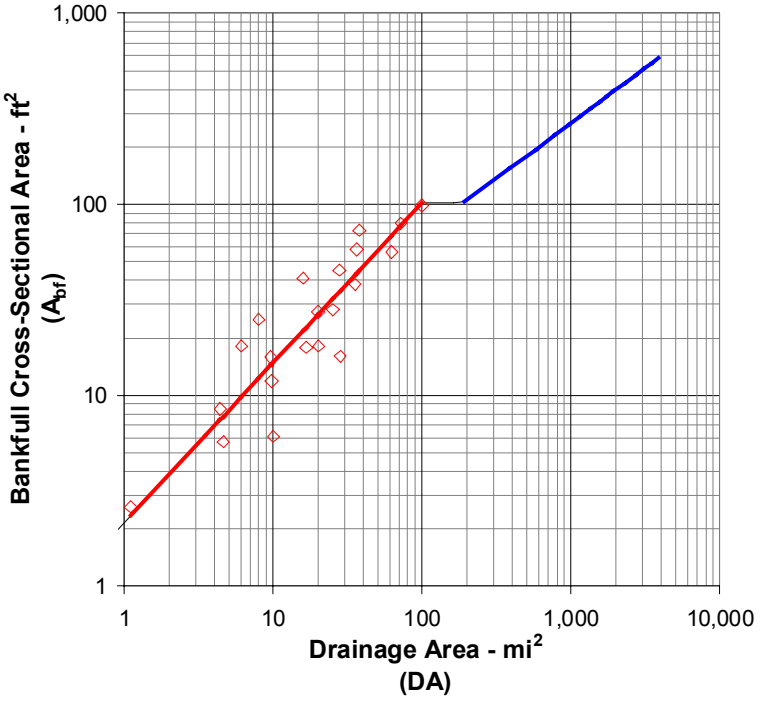
Relate bankfull cross-sectional area to drainage area

Substituting the Bakke et al. regional curve relationships for bankfull discharge into the DEQ derived relationship for bankfull cross-sectional area and bankfull discharge allows bankfull cross-sectional area to be expressed as a function for all drainage areas.

The two bankfull discharge regional curve relationships presented by Bakke et al. are accounted for in the figure below and produce two relationships for bankfull cross-sectional area: less than (100 mi^2) 260 km^2 and greater than (193 mi^2) 500 km^2. The area between the two curves is simply the highest value of the less than 260 km^2 relationship extended to the greater than 500 km^2 relationship. Since the two relationships predict different values for the 260 km^2 to 500 km^2 region of the curve, the higher values are used.

Bankfull Cross-Sectional Area v. Drainage Area

Regional curve for bankfull cross-sectional area and drainage area – Klamath Basin and surround area stream systems (data from Bakke et al., 2000, DEQ analysis)



For DA < 260 km^2 (100 mi^2)

Metric Units

$A_{bf} = 0.0905 \cdot DA^{0.8369}$

English Units

$A_{bf} = 2.1603 \cdot DA^{0.8369}$

n = 21, $R^2 = 0.80$

Se = 0.19 m^2 (2.05 ft^2)

F Statistic = 80

Significant at 0.05

For DA 260 km^2 (100 mi^2) to 500 km^2 (193 mi^2)

A_{bf} = 9.5 m^2 (102.3 ft^2)

For DA > 500 km^2 (193 mi^2)

Metric Units

$A_{bf} = 0.2669 \cdot DA^{0.5766}$

English Units

$A_{bf} = 4.9731 \cdot DA^{0.5766}$

Channel Width Assessment

Step 7
Methodology Overview

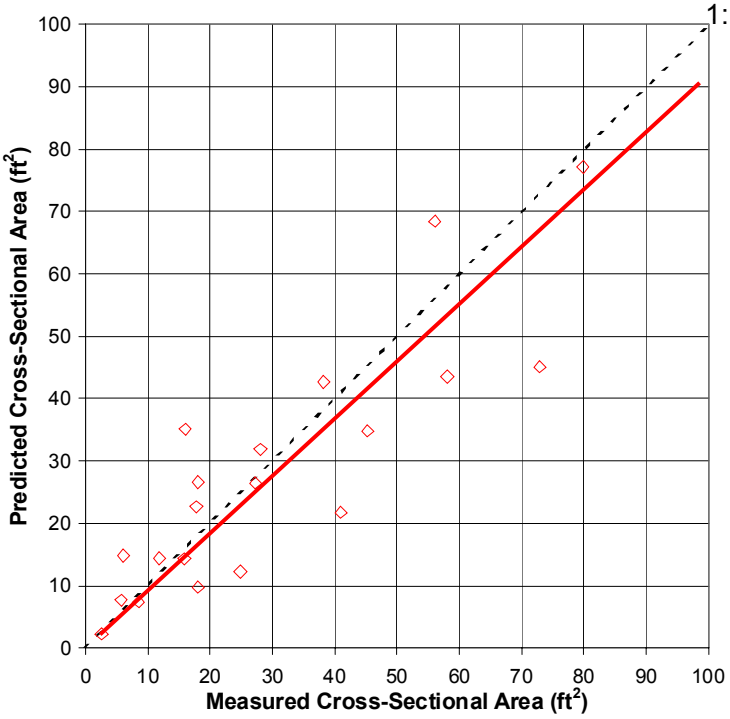
Metric Units	*English Units*
A_{bf}: Bankfull Cross-Sectional Area (m^2) DA: Drainage Area (km^2) Q_{bf}: Bankfull Discharge (m^3/s)	A_{bf}: Bankfull Cross-Sectional Area (ft^2) DA: Drainage Area (mi^2) Q_{bf}: Bankfull Discharge (ft^3/s)
Step 4 Bankfull Discharge as a Function of Drainage Area, For all DA < 260 km^2 $Q_{bf} = 0.0272 \cdot DA^{1.0740}$ ($R^2 = 0.91$) For all DA > 260 km^2 $Q_{bf} = 0.1090 \cdot DA^{0.7400}$ ($R^2 > 0.99$) (Bakke et al., 2000)	**Step 4** Bankfull Discharge as a Function of Drainage Area, For all DA < 100 mi^2 $Q_{bf} = 2.6694 \cdot DA^{1.0740}$ ($R^2 = 0.91$) For all DA > 100 mi^2 $Q_{bf} = 7.7843 \cdot DA^{0.7400}$ ($R^2 > 0.99$) (DEQ analysis)
Step 5 Bankfull Cross-Sectional Area as a Function of Bankfull Discharge, $A_{bf} = 1.5009 \cdot Q_{bf}^{0.7792}$ (DEQ analysis)	**Step 5** Bankfull Cross-Sectional Area as a Function of Bankfull Discharge, $A_{bf} = 1.0050 \cdot Q_{bf}^{0.7792}$ (DEQ analysis)
Step 6 Bankfull Cross-Sectional Area as a Function of Drainage Area, For all DA < 260 km^2 $A_{bf} = 1.5009 \cdot (0.0272 \cdot DA^{1.0740})^{0.7792}$ *Which simplifies to,* $A_{bf} = 0.0905 \cdot DA^{0.8369}$ ($R^2 = 0.92$) DA < 260 km^2 to 500 km^2 Regression Equations Predict Differing Values. Use higher range of values. $A_{bf} = 9.5\ m^2$ DA < 500 km^2 $A_{bf} = 1.5009 \cdot (0.1090 \cdot DA^{0.740})^{0.7792}$ *Which simplifies to,* $A_{bf} = 0.2669 \cdot DA^{0.5766}$ (DEQ analysis)	**Step 6** Bankfull Cross-Sectional Area as a Function of Drainage Area, For all DA < 100 mi^2 $A_{bf} = 2.1603 \cdot DA^{0.8369}$ ($R^2 = 0.92$) DA < 100 mi^2 to 193 mi^2 Regression Equations Predict Differing Values. Use higher range of values. $A_{bf} = 102.3\ ft^2$ DA < 193 mi^2 $A_{bf} = 4.9731 \cdot DA^{0.5766}$ (DEQ analysis)

Channel Width Assessment

Step 8
Validate Methodology

The accuracy of predicting the bankfull cross-sectional area as a function of drainage area is presented in the figure below. It should be noted that validation of the DEQ derived curve for drainage areas greater than 500 km^2 is not possible due to lack of data. There is an implicit assumption that the relationship between bankfull discharge and bankfull cross-sectional area is valid throughout the range of drainage areas analyzed by this approach (0 to 10,000 km^2).

Cross-Sectional Area Validation
Predicted v. Measured
Channel cross-sectional area - Measured vs. precited – Klamath Basin and surrounding area stream systems (data from Bakke et al., 2000, DEQ analysis).



For DA < 260 km^2 (100 mi^2)

$A_{predicted} = 0.9353 \cdot A_{measured}$

n = 21, R^2 = 0.92
Se = 0.98 m^2 (10.55 ft^2)
F Statistic = 215
Significant at 0.05

Channel Width Assessment

Step 9

Relate Bankfull Width Values to Stream Type, Width to Depth and Drainage Area

Bankfull width can be estimated as a function of width to depth ratio and cross-sectional area.

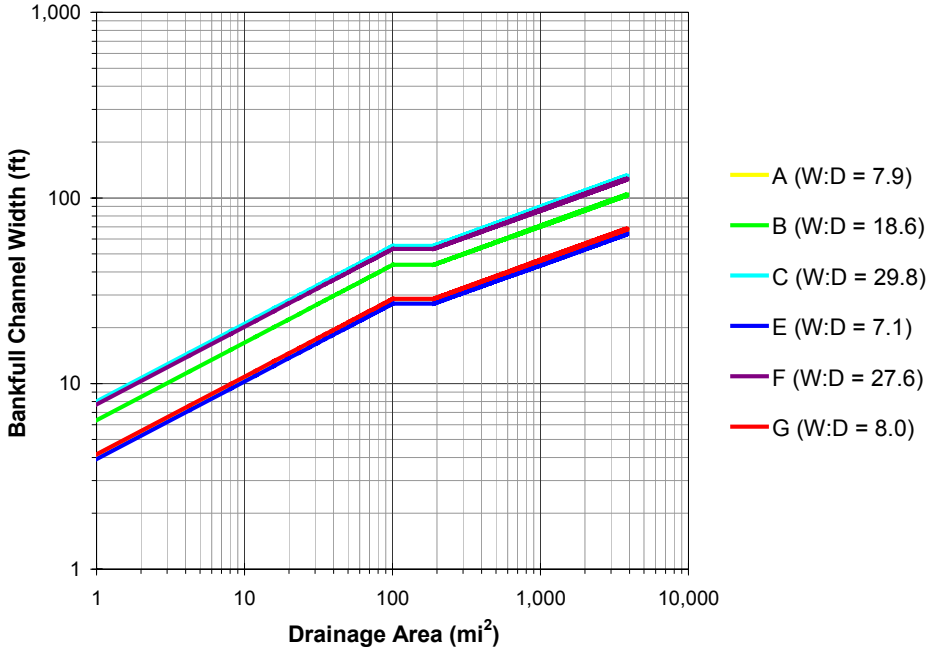
$$BFW = \sqrt{W:D \cdot A_{bf}}$$

(Rosgen, 1996)

Using this relationship for bankfull width, it is possible to relate bankfull width to drainage area and width to depth ratios. This relationship is used for a best fit to measured NSDZ width data. Drainage areas for all stream data nodes are calculated from 30-meter digital elevation model data. Width to depth ratios are the variable used as the basis for the best fit relationship. All derived width to depth ratios are within published ranges for level I stream types (Rosgen, 1996).

Level I Stream Type	Width to Depth
A	7.9
B	18.6
C	29.8
D	N/A
E	7.1
F	27.6
G	8.0

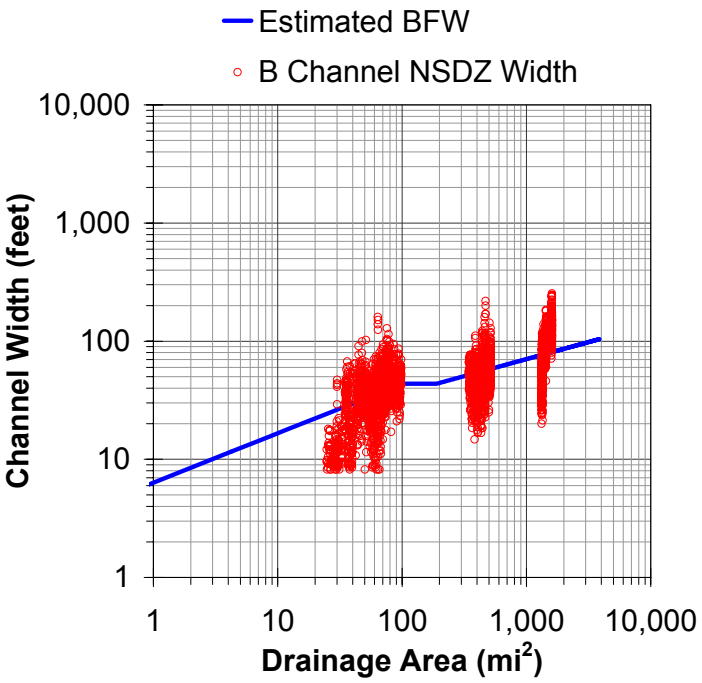
Bankfull Width as a Function of Width to Depth Ratio and Drainage Area



Channel Width Assessment

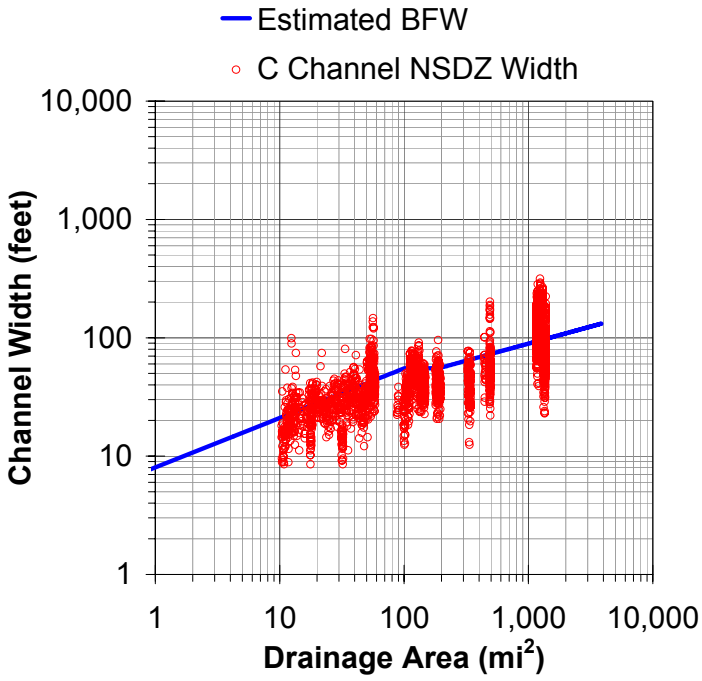
Step 9 (continued)

Relate Bankfull Width Values to Stream Type, Width to Depth and Drainage Area



B Channel Regression Analysis for Average W:D = 18.6

n = 4,032, R^2 = 0.60
Se = 7.8 m (25.5 ft)
F Statistic = 146
Significant at 0.05



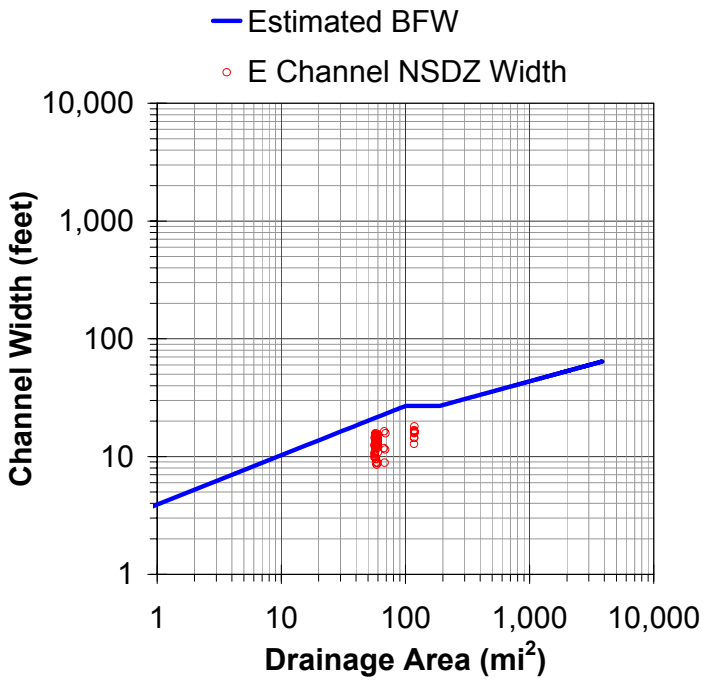
C Channel Regression Analysis for Average W:D = 29.8

n = 10,547, R^2 = 0.54
Se = 12.3 m (40.4 ft)
F Statistic = 581
Significant at 0.05

Channel Width Assessment

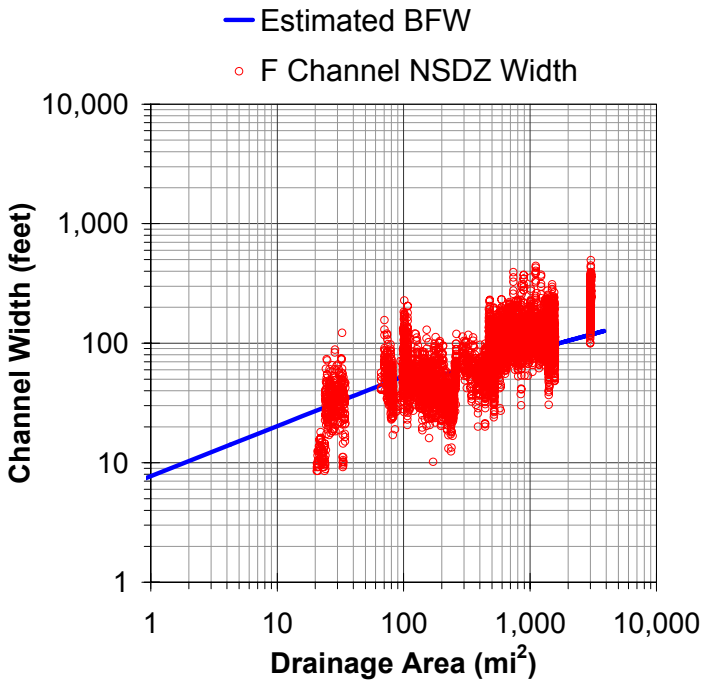
Step 9 (continued)

Relate Bankfull Width Values to Stream Type, Width to Depth and Drainage Area



E Channel Regression Analysis for Average W:D = 7.1

n = 56, R^2 = 0.20
Se = 10.0 m (32.8 ft)
F Statistic = 74
Not Significant at 0.05



F Channel Regression Analysis for Average W:D = 27.6

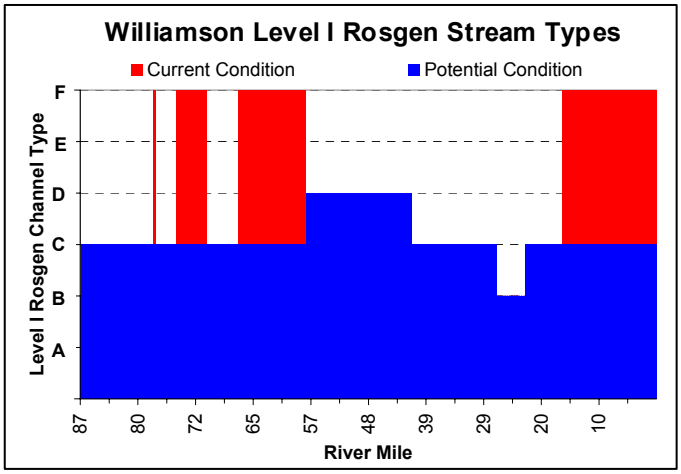
n = 7,373, R^2 = 0.55
Se = 12.3 m (40.4 ft)
F Statistic = 883
Significant at 0.05

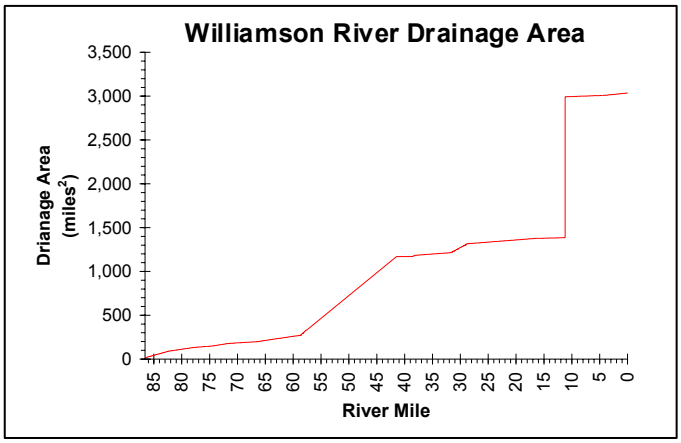
Channel Width Assessment

Step 10
Develop Potential Channel Width as a Function of Stream Type, Width to Depth Ratios and Drainage Area

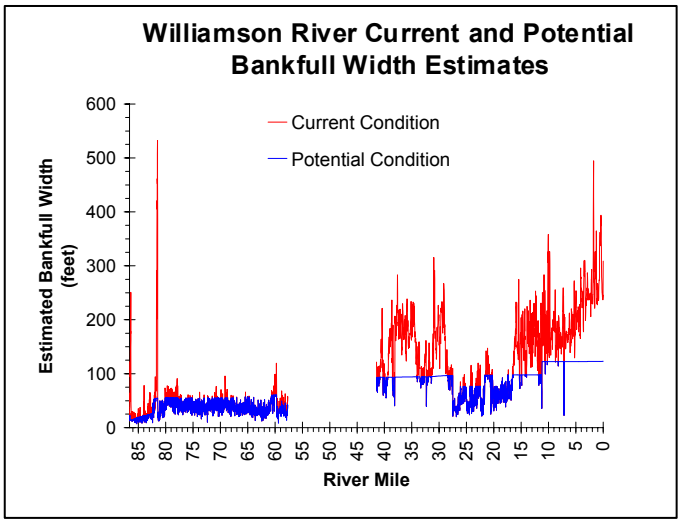
Rosgen (1996) outlines a methodology for analyzing channel evolution. Drawing from this methodology ODEQ estimated the potential for change with stream channel types. A, B, C and E stream types are considered in a stable condition with little chance for change to another stream type. D channels are braided, resulting from natural and/or human disturbance process. In some cases D channels can change to C or E stream types provided sediment supply and stream morphology allows. All F stream types are considered below potential and changed to either C or E types, depending on the contributing drainage area.

Current Condition	Potential Condition
A	A
B	B
C	C or E
D	C, D or E
E	E
F	C or E





Using regional curve relationships for bankfull width (**developed in Step 9**) as a threshold condition, departures above this threshold become evident. Potential bankfull widths are developed by simply targeting bankfull width values at or below the regional curve threshold for the appropriate stream type. In essence the potential stream type and width to depth ratio is targeted.



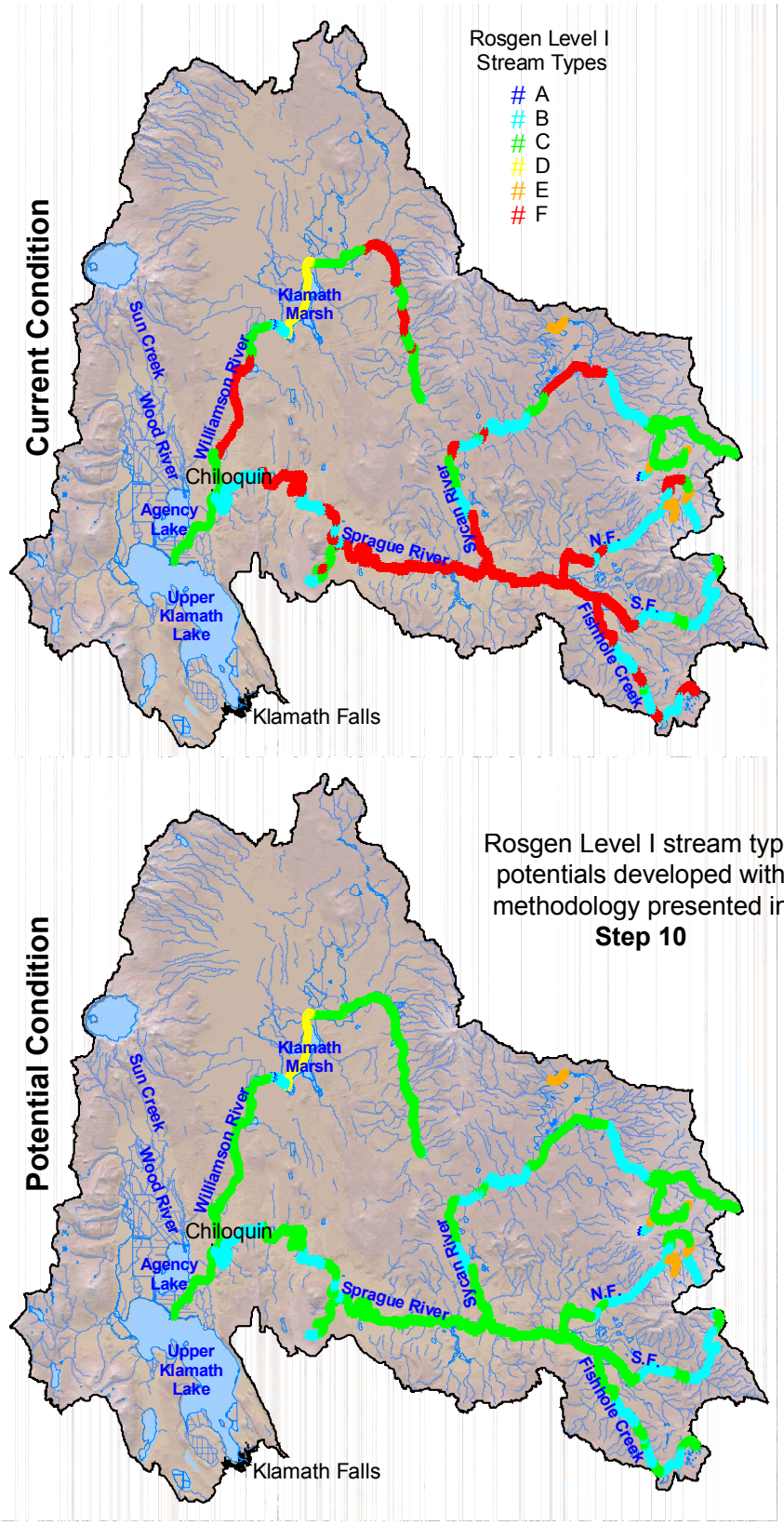
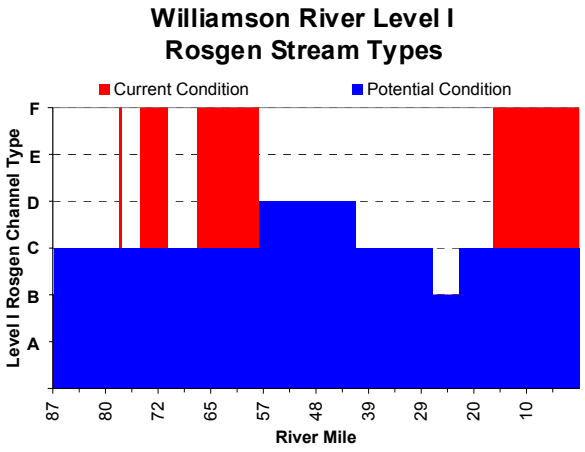
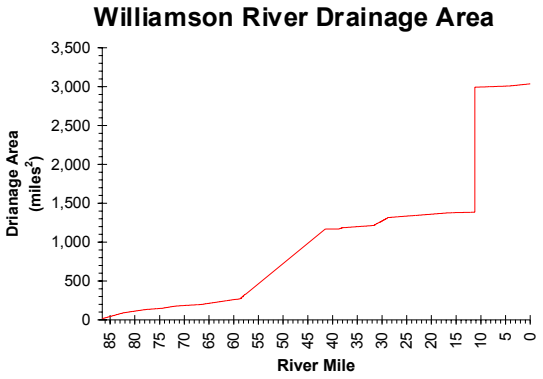


***Figure 3.10**. Rosgen stream types (level I) - current and potential conditions.*

3.4.5 Bankfull Width Estimates (Current and Potential Conditions)





$$BFW = \sqrt{W:D \cdot A_{bf}} \quad \text{(Rosgen, 1996)}$$

Where,
W:D - Estimated in **Step 9**
X_{Area} - Estimated in **Step 6**

Level I Stream Type	Width to Depth
A	7.9
B	18.6
C	29.8
D	N/A
E	7.1
F	27.6
G	8.0

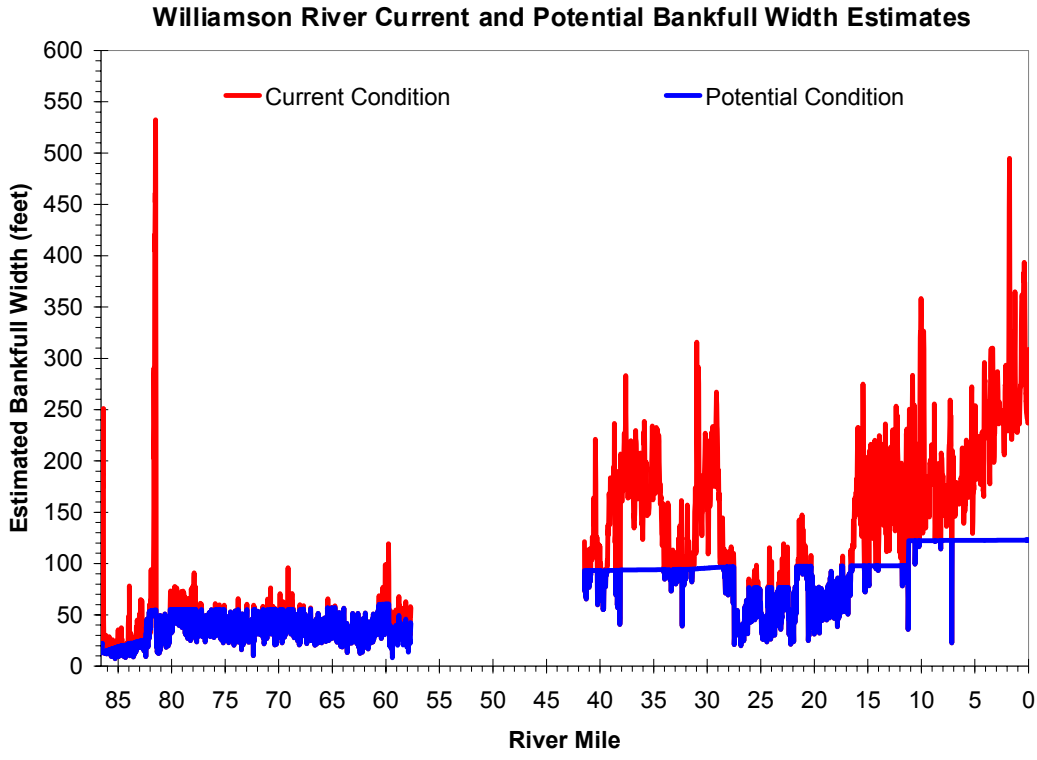
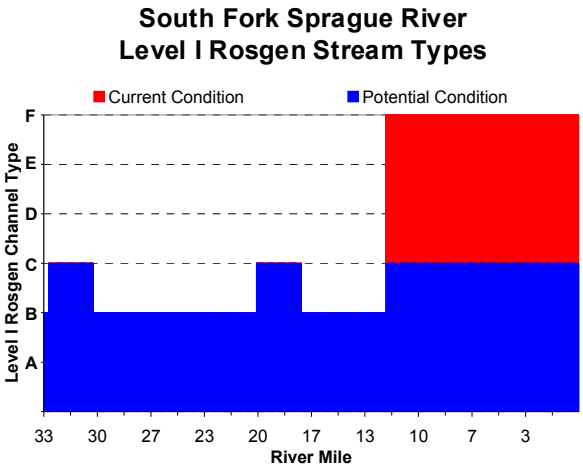
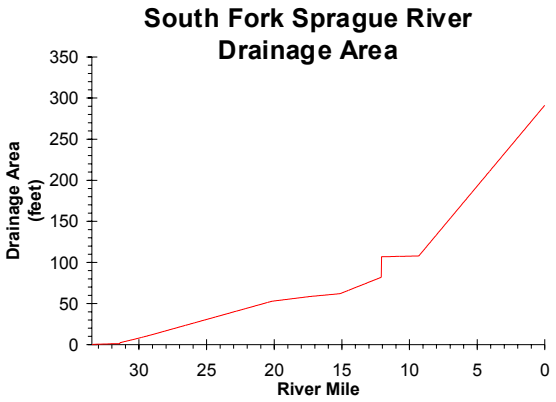


***Figure 3.11**. Williamson River bankfull width estimates for current and potential conditions.*





$$BFW = \sqrt{W:D \cdot A_{bf}}$$ (Rosgen, 1996)

Where,
W:D - Estimated in **Step 9**
X_{Area} - Estimated in **Step 6**

Level I Stream Type	Width to Depth
A	7.9
B	18.6
C	29.8
D	N/A
E	7.1
F	27.6
G	8.0

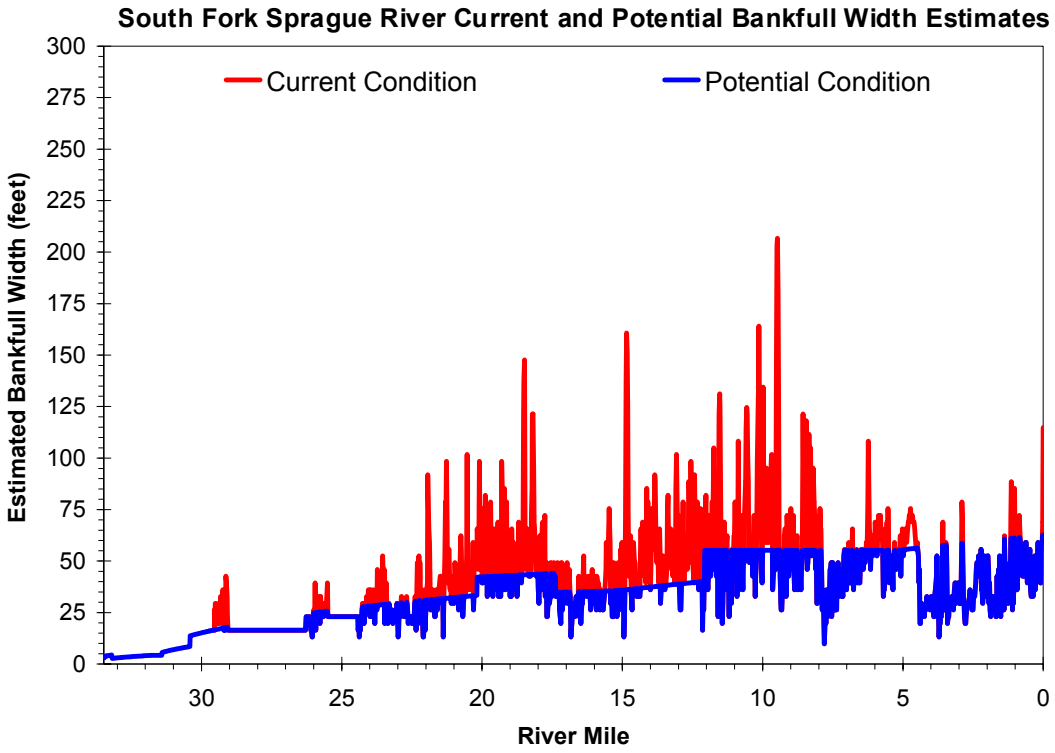
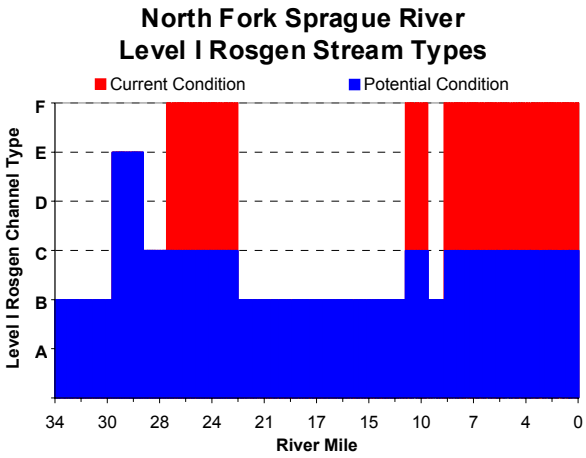
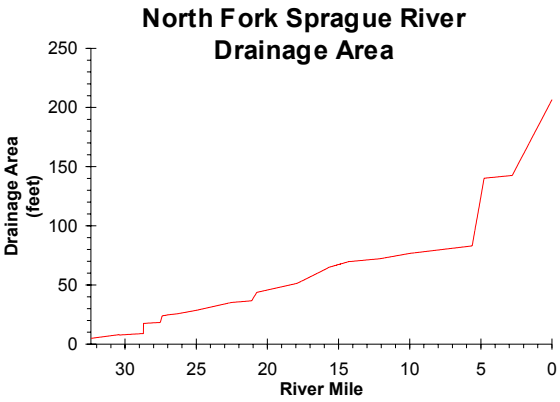


***Figure 3.12**. South Fork Sprague River bankfull width estimates for current and potential conditions.*





$$BFW = \sqrt{W:D \cdot A_{bf}} \quad \text{(Rosgen, 1996)}$$

Where,
W:D - Estimated in **Step 9**
X_{Area} - Estimated in **Step 6**

Level I Stream Type	Width to Depth
A	7.9
B	18.6
C	29.8
D	N/A
E	7.1
F	27.6
G	8.0

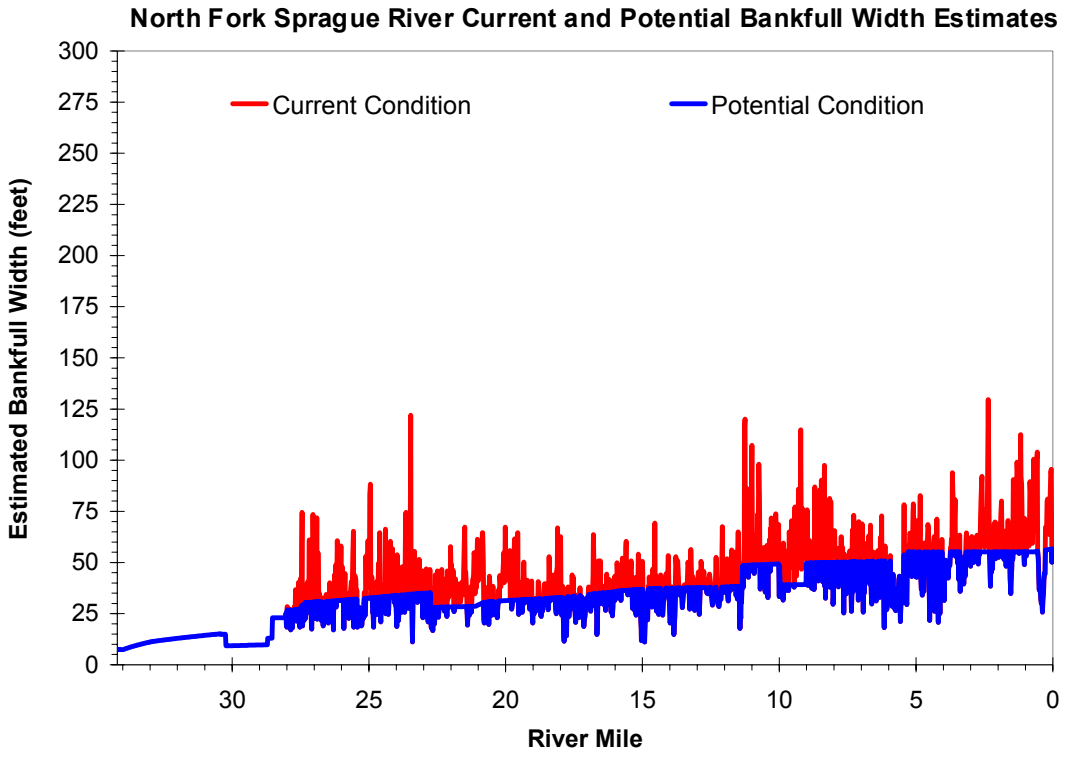
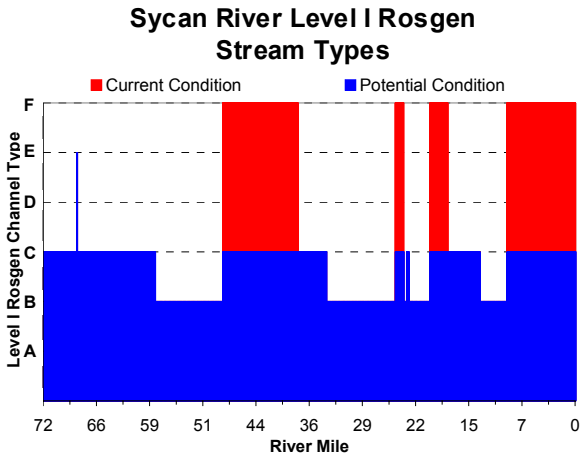
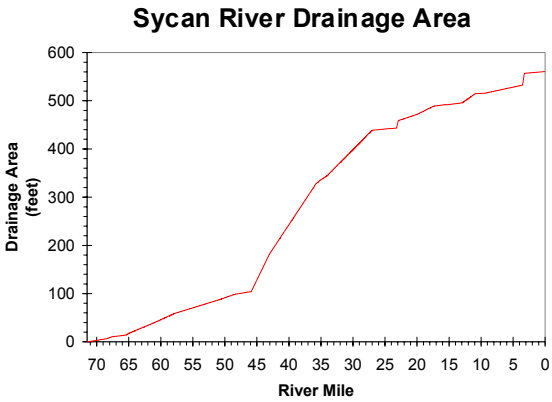


***Figure 3.13**. North Fork Sprague River bankfull width estimates for current and potential conditions.*





$$BFW = \sqrt{W:D \cdot A_{bf}} \quad \text{(Rosgen, 1996)}$$

Where,

W:D - Estimated in **Step 9**

X_{Area} - Estimated in **Step 6**

Level I Stream Type	Width to Depth
A	7.9
B	18.6
C	29.8
D	N/A
E	7.1
F	27.6
G	8.0

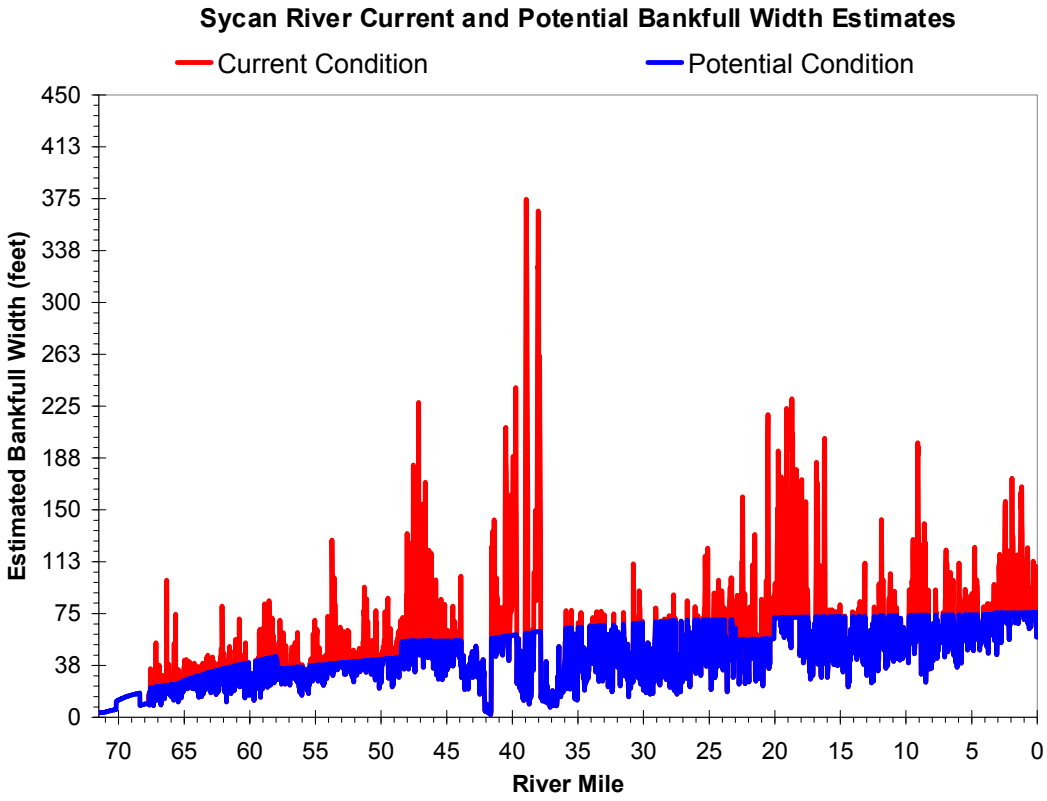
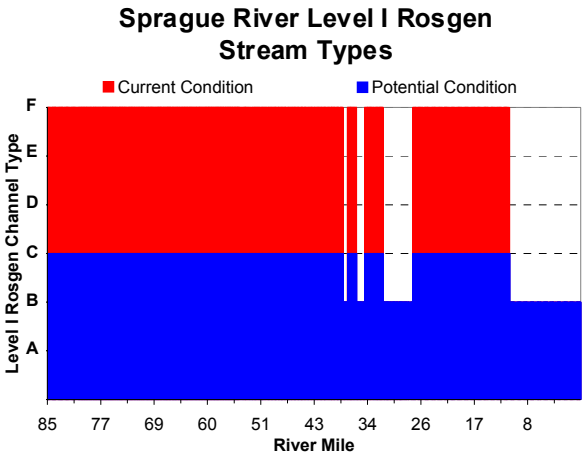
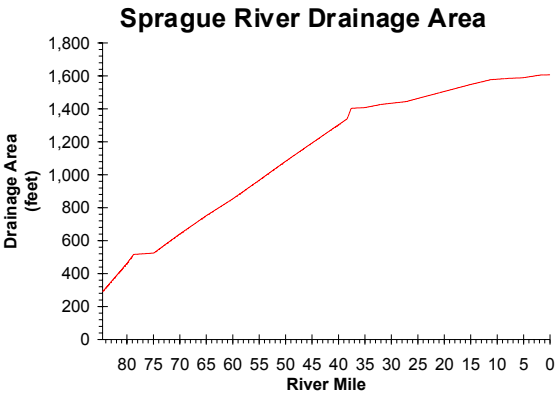


***Figure 3.14**. Sycan River bankfull width estimates for current and potential conditions.*





$$BFW = \sqrt{W:D \cdot A_{bf}} \quad \text{(Rosgen, 1996)}$$

Where,
W:D - Estimated in **Step 9**
X_{Area} - Estimated in **Step 6**

Level I Stream Type	Width to Depth
A	7.9
B	18.6
C	29.8
D	N/A
E	7.1
F	27.6
G	8.0

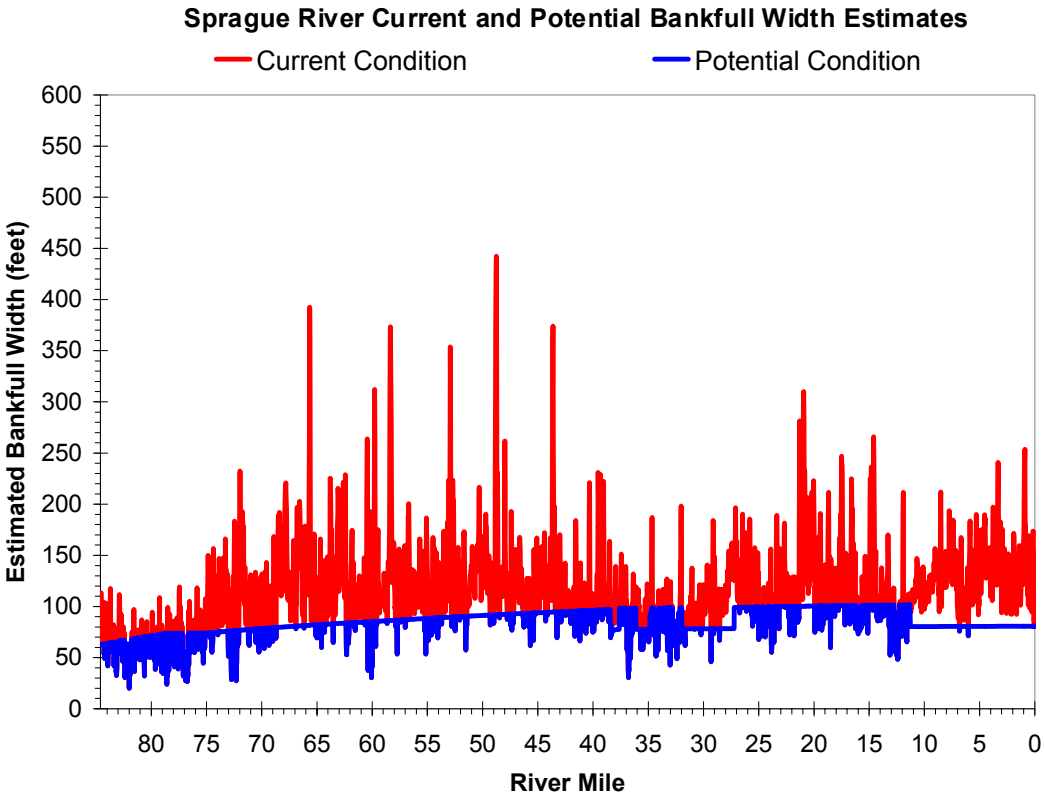


***Figure 3.15**. Sprague River bankfull width estimates for current and potential conditions.*

3.5 Near Stream Land Cover

3.5.1 Near Stream Land Cover - Overview

The role of near stream land cover in maintaining a healthy stream condition and water quality is well documented and accepted in scientific literature (Beschta et al. 1987). The list of important impacts that near stream land cover has upon the stream and the surrounding environment is long and warrants listing.

- Near stream land cover plays an important role in regulating radiant heat in stream thermodynamic regimes.
- Channel morphology is often highly influenced by land cover type and condition by affecting flood plain and instream roughness, contributing coarse woody debris and influencing sedimentation, stream substrate compositions and stream bank stability.
- Near stream land cover creates a thermal microclimate that generally maintains cooler air temperatures, higher relative humidity and lower wind speeds along stream corridors.
- Riparian and instream nutrient cycles are affected by near stream land cover.

With the recognition that near stream land cover is an important parameter in influencing water quality, ODEQ made the development of land cover data sets in the Upper Klamath Lake drainage a high priority. Variable land cover conditions in the Upper Klamath Lake drainage require a higher resolution than currently available GIS data sources. To meet this need, Oregon DEQ has mapped near stream land cover using rectified color aerial imagery at a 1:5,000 scale. Land cover features were mapped 300 feet in the transverse direction from each stream bank. Land cover data is developed by ODEQ in six successive steps.

Step 1. Land cover polygons and stream polylines are digitized from 1998 color aerial photos. All digitized polygons are drawn to capture visually like land cover features. All digitized line work is completed at 1:5,000 or less.

Step 2. Basic land cover types are developed and assigned to individual polygons. The land cover types used in this effort are aggregate land cover groups, such as: conifers, hardwoods, shrubs, etc.

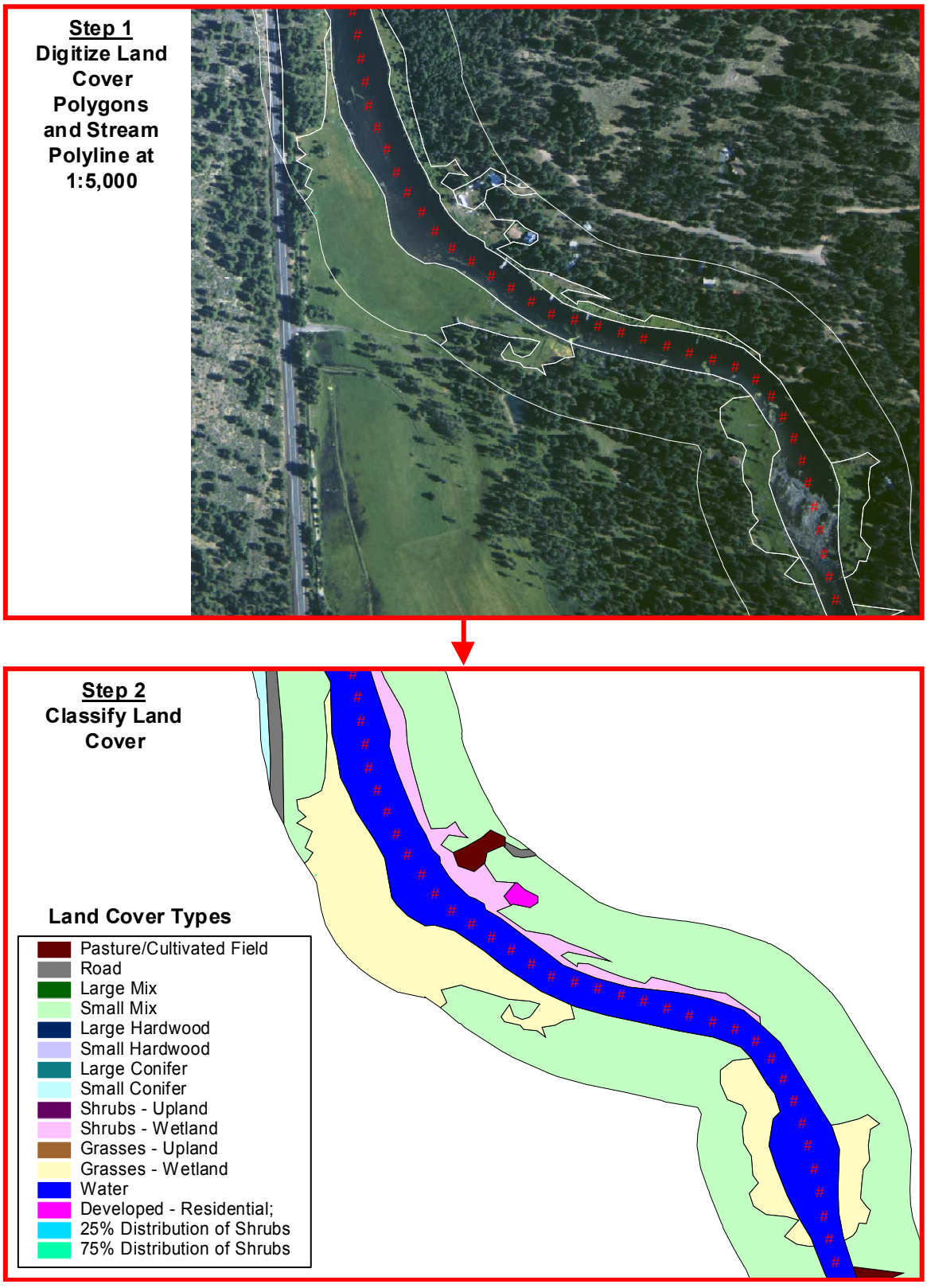
Step 3. Through simple assumptions regarding land cover succession and by examining land cover types adjacent to major anthropogenic disturbance areas (i.e. clearcuts, roads, cultivated fields, etc.), it is possible to develop a rule set that can be used to estimate potential land cover conditions. For example, small conifers are assumed to have the potential to become large conifers. A high and low range is developed in areas where uncertainty remains about land cover succession or the potential for recovery.

Step 4. Automated sampling is conducted on classified land cover spatial data sets in 2-dimensions. Every 100 feet along the stream (i.e. in the longitudinal direction), both stream banks are sampled every 15 feet, starting at the channel edge, out to 135 feet. This sampling rate results in 950 measurements of land cover per every mile of stream.

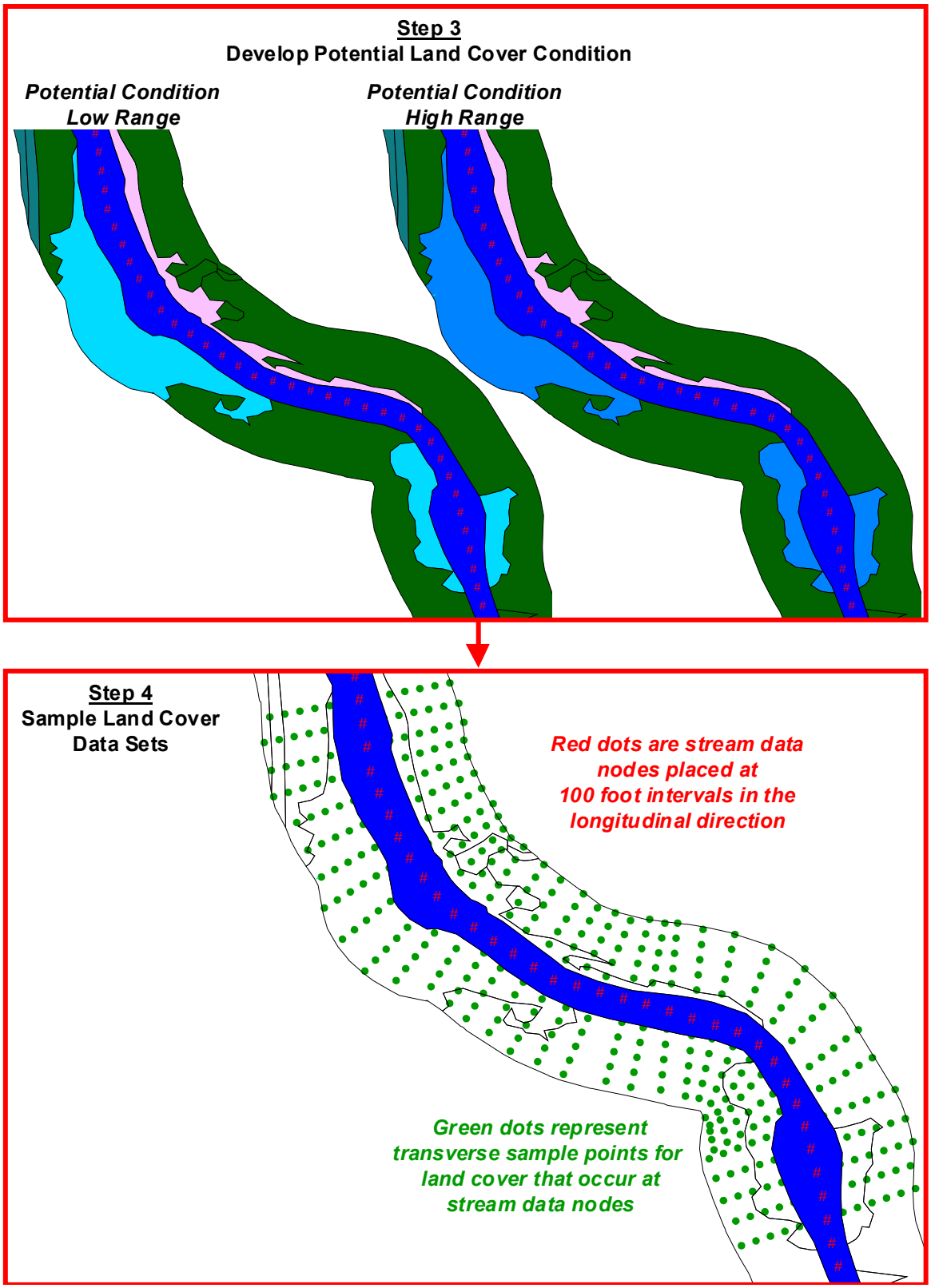
Step 5. Ground level land cover data is statistically summarized and sorted by land cover type. Median values for land cover height and density can then be used to describe land cover classifications.

Step 6. Land cover physical attributes can then be described in 2-dimensions since automated sampling occurs in both the longitudinal and transverse directions.

Near Stream Land Cover Data Development



Near Stream Land Cover Data Development

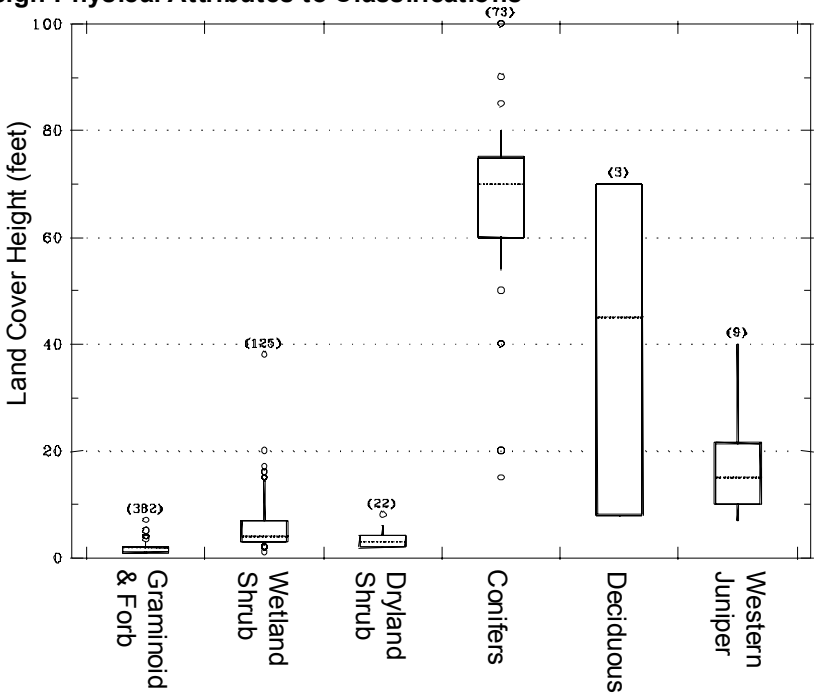


Near Stream Land Cover Data Development

Step 5

Assign Physical Attributes to Classifications

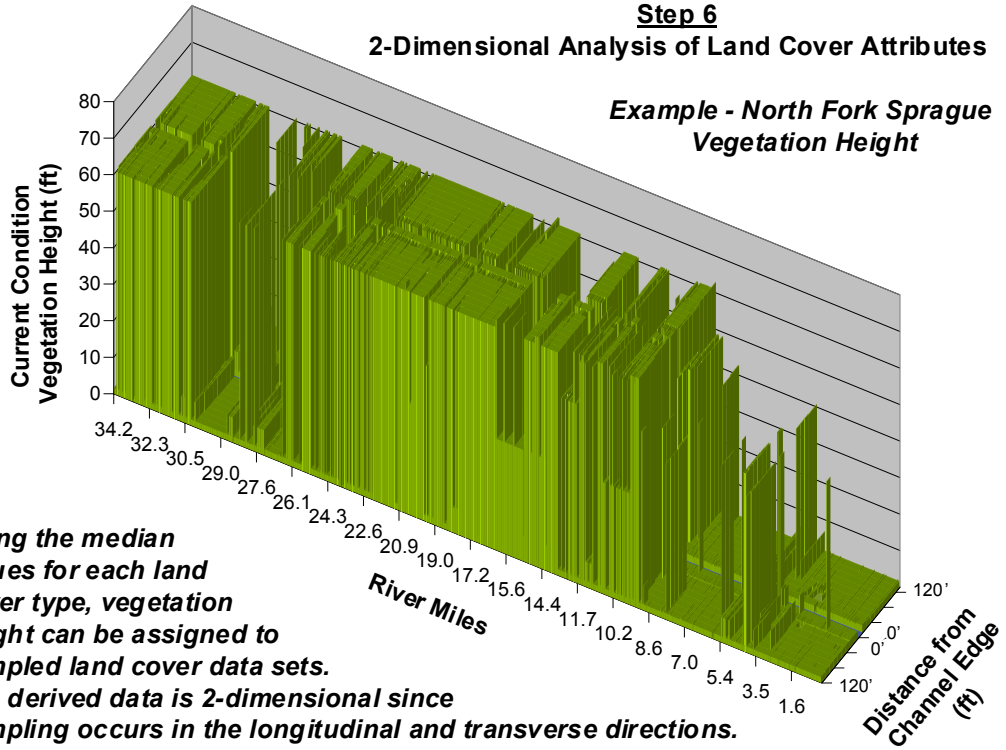
Ground level land cover data is statistically summarized and sorted by vegetation type. Median values allow a general description based on site specific data collected in the study area. Vegetation height is used here as an example.



Step 6

2-Dimensional Analysis of Land Cover Attributes

Example - North Fork Sprague Vegetation Height



Using the median values for each land cover type, vegetation height can be assigned to sampled land cover data sets. The derived data is 2-dimensional since sampling occurs in the longitudinal and transverse directions.

3.5.2 Near Stream Land Cover - Mapping, Classification and Sampling

The USFS collected riparian species, height, and density data at 56 sites in the Sprague River subbasin and the Williamson River subbasin during 1999. Data sampled at these sites resulted in 616 discrete land cover species identifications and height measurements. ODEQ grouped land cover species into land cover types, such as: graminoid/forb, shrub, other confers, western junipers and deciduous trees. Data were then statistically summarized by land cover type to determine the average land cover heights and variability within the data stratification. As would be expected, variability in height increased with taller growing land cover types. A possible weakness in the data set is the relatively small samples of deciduous land cover and high variability with this grouping. It is unclear from the data whether variability is high or simply an artifact of the small number of samples. Further, it is unclear whether the absence of deciduous samples indicates rarity of deciduous land cover within near stream areas. **Table 3-2** presents summarized land cover height statistics derived from USFS data.

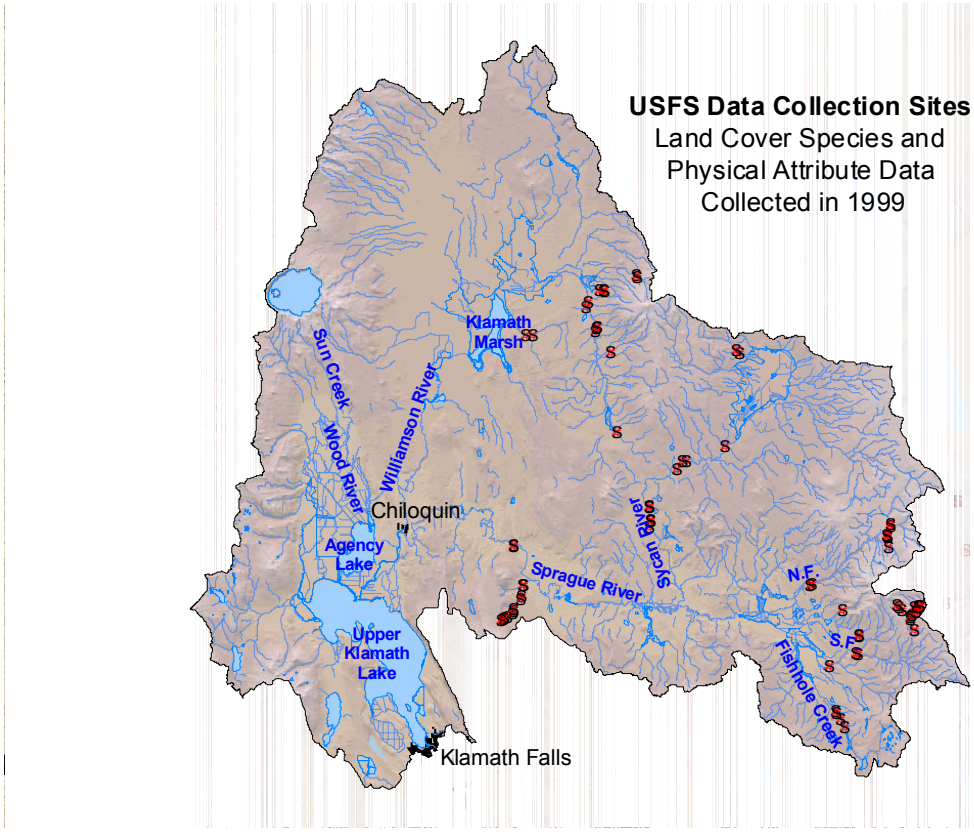


Table 3-2. Land cover Summary Statistics (USFS land cover data)

Land cover Type	Samples	Median Height (feet)	Average Height (feet)	Standard Deviation (feet)	Maximum Height (feet)	Minimum Height (feet)
Graminoid/Forb	362	2.0	1.8	0.9	7.0	0.3
Wetland Shrub	125	4.0	6.3	5.0	38.0	1.0
Dryland Shrub	22	3.0	3.4	1.7	8.0	1.0
Western Juniper	9	15.0	17.6	10.0	40.0	7.0
Other Conifer	73	70.0	66.7	14.9	100.0	15.0
Deciduous	3	45.0	41.0	31.2	70.0	8.0

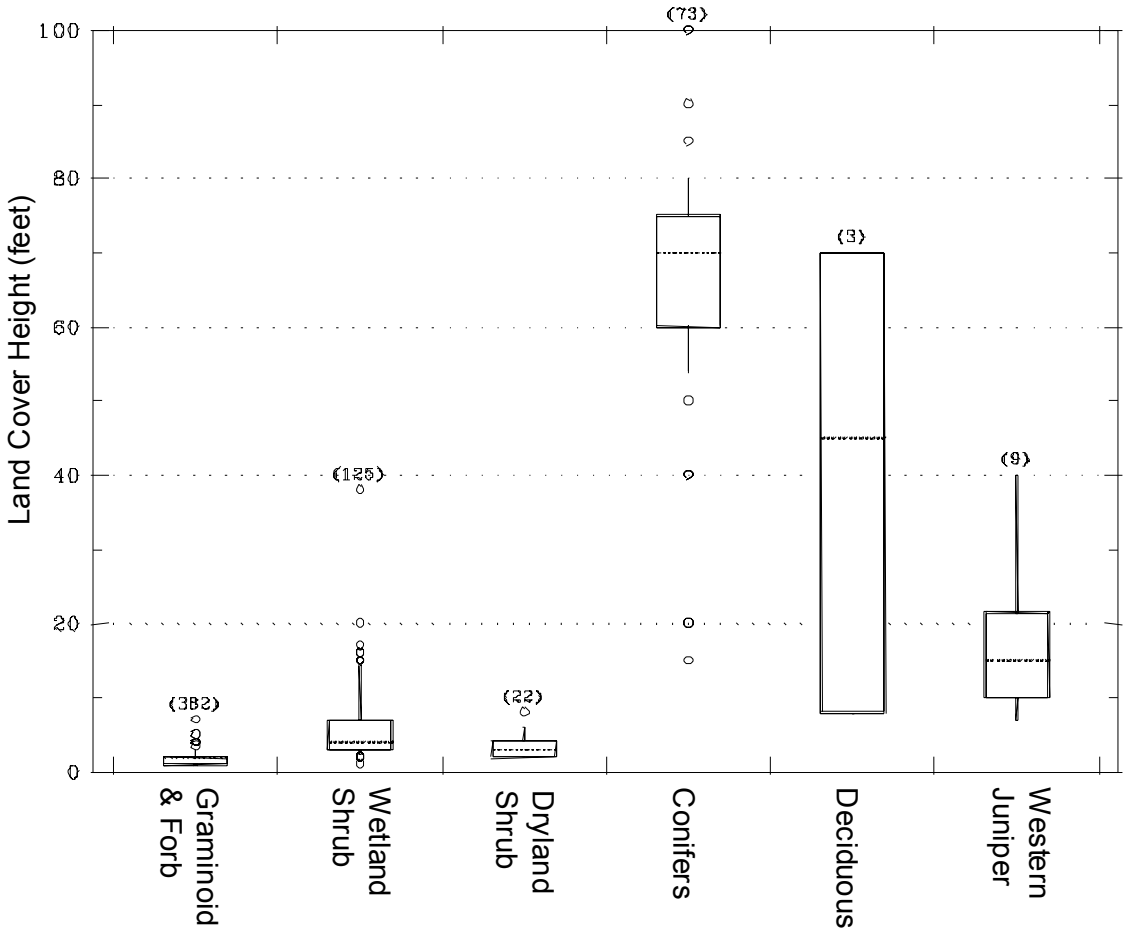


***Figure 3-16**. Summarized land cover height data (USFS data).*

Land cover and land cover classifications developed by ODEQ are presented in **Table 3-3**. These classifications were developed using the following criteria/assumptions:

- Average statistics developed from USFS ground level data (**Table 3-2**) are used to assign land cover height and density classifications.
- Several land cover classifications assumed zero height, density and overhang attributes. These include all classifications for barren, water, channel bottom, and instream structures (dam/weir/canal).
- Development classification attempts to estimate heights and density (100%) of structures (e.g. houses, buildings, etc.)
- Overhanging land cover refers to the horizontal distance that land cover occupies from the channel edge extending over the stream channel. These values are assumed as follows:

Conifer Overhanging Distance =	10.0% land cover Height
Hardwood Overhanging Distance =	15.0% land cover Height
Mixed Conifer/Hardwood Overhanging Distance =	12.5% land cover Height
Non-Woody Land cover Overhanging Distance =	50.0% land cover Height

Table 3-3. ODEQ Vegetation and Land Cover Classifications for Digitized Polygons

Classification Code	Land Cover Description	Land cover Height (feet)	Land cover Density	Overhanging Land cover (feet)
301	Water	0.0	0%	0.0
302	Pastures/Cultivated Field/lawn	1.6	75%	1.0
304	Barren - Rock	0.0	0%	0.0
305	Barren - Embankment	0.0	0%	0.0
308	Barren - Clearcut	0.0	0%	0.0
309	Barren - Soil	0.0	0%	0.0
400	Barren - Road	0.0	0%	0.0
401	Barren - Forest Road	0.0	0%	0.0
500	L. Mixed Conifer/Deciduous	53.8	60%	6.9
501	S. Mixed Conifer/Deciduous	26.9	60%	3.3
550	L. Mixed Conifer/Deciduous	53.8	30%	6.9
551	S. Mixed Conifer/Deciduous	26.9	30%	3.3
555	L. Mixed Conifer/Deciduous	53.8	10%	6.9
600	Large Deciduous	41.0	75%	6.2
601	Small Deciduous	20.3	75%	3.0
650	Large Deciduous	41.0	30%	6.2
651	Small Deciduous	20.3	30%	3.0
655	Large Deciduous	41.0	10%	6.2
700	Large Conifer	66.6	60%	6.6
701	Small Conifer	33.5	60%	3.3
750	Large Conifer	66.6	30%	6.6
751	Small Conifer	33.5	30%	3.3
755	Western Juniper	17.7	10%	1.6
800	Upland shrubs	5.9	75%	1.0
801	Wetland Shrubs	5.9	75%	1.0
850	Dryland Shrubs	5.9	25%	1.0
851	Wetland Shrubs	5.9	25%	1.0
900	Wetland Grasses	1.6	75%	1.0
901/902	Dryland Grasses	1.6	75%	1.0
3011	Active Channel Bottom	0.0	0%	0.0
3248	Development – Residential	20.0	100%	0.0
3249	Development – Industrial	29.9	100%	0.0
3252	Dam/Wier	0.0	0%	0.0
3255	Canal	0.0	0%	0.0
3256	Dike	0.0	0%	0.0
1	Klamath Marsh Area	1.6	90%	1.0

Table 3-4. USFS Land cover Data

USFS Site	Land cover Type	Land cover Name	Height (feet)	USFS Site	Land cover Type	Land cover Name	Height (feet)
WSW018P	Graminoids/Forb	Agrostis	3.0	PPW325P	Graminoids/Forb	Canadian Goldenrod	2.0
WSW019P	Graminoids/Forb	Agrostis	1.0	Sycan36	Graminoids/Forb	Canadian Goldenrod	3.0
LPN049P	Graminoids/Forb	Agrostis	2.0	PPM062P	Graminoids/Forb	Canadian Goldenrod	2.0
LPM059P	Graminoids/Forb	Agrostis	3.0	PPW066P	Graminoids/Forb	Canadian Goldenrod	2.0
PPM062P	Graminoids/Forb	Agrostis	1.5	PPM068P	Graminoids/Forb	Canadian Goldenrod	1.0
PPM064P	Graminoids/Forb	Agrostis	2.0	ARW027P	Graminoids/Forb	Canby's Licorice Root	2.0
PPW066P	Graminoids/Forb	Agrostis	1.5	SGW004P	Graminoids/Forb	Creeping Spike Rush	2.0
PPM067P	Graminoids/Forb	Agrostis	2.0	SGW010P	Graminoids/Forb	Creeping Spike Rush	2.0
PPN069P	Graminoids/Forb	Agrostis	2.5	SGW011P	Graminoids/Forb	Creeping Spike Rush	2.0
ARW031P	Graminoids/Forb	Agrostis Spp	1.5	SGW013P	Graminoids/Forb	Creeping Spike Rush	2.0
LPM053P	Graminoids/Forb	Agrostis Spp	1.5	WSW023P	Graminoids/Forb	Creeping Spike Rush	2.0
WSN014P	Graminoids/Forb	Alder Buckthorn	7.0	WSW025P	Graminoids/Forb	Creeping Spike Rush	2.0
WSM022P	Graminoids/Forb	Alpine Shooting Star	0.5	LPW051P	Graminoids/Forb	Creeping Spike Rush	2.5
WSW017P	Graminoids/Forb	Alpine Timothy	1.0	LPW057P	Graminoids/Forb	Creeping Spike Rush	2.0
LPW050P	Graminoids/Forb	American Brooklime	1.0	LPW058P	Graminoids/Forb	Creeping Spike Rush	2.0
WSN400P	Graminoids/Forb	American Brookline	1.0	PPW325P	Graminoids/Forb	Creeping Spike Rush	2.5
ARW027P	Graminoids/Forb	American Vetch	2.0	Sycan40	Graminoids/Forb	Creeping Spike Rush	3.0
PPM068P	Graminoids/Forb	American Vetch	1.0	SGW005P	Graminoids/Forb	Crimson Columbine	2.0
PPN069P	Graminoids/Forb	American Vetch	2.0	SGW004P	Graminoids/Forb	Curly Dock	1.0
PPN065P	Graminoids/Forb	Annual Hairgrass	1.0	SGW006P	Graminoids/Forb	Curly Dock	1.0
SGW002P	Graminoids/Forb	Aquatic Sedge	4.0	LPM053P	Graminoids/Forb	Curly Dock	3.0
SGW003P	Graminoids/Forb	Aquatic Sedge	2.0	PPN065P	Graminoids/Forb	Dewsy's Sedge	1.0
SGW005P	Graminoids/Forb	Aquatic Sedge	1.5	ARM026P	Graminoids/Forb	Enchanters Night Shade	0.3
SGN007P	Graminoids/Forb	Aquatic Sedge	1.0	ARN029P	Graminoids/Forb	Enchanters Night Shade	0.3
SGM012P	Graminoids/Forb	Aquatic Sedge	1.5	SGN000P	Graminoids/Forb	Field Mint	1.0
SGM400P	Graminoids/Forb	Aquatic Sedge	1.5	SGW002P	Graminoids/Forb	Field Mint	0.5
WSN014P	Graminoids/Forb	Aquatic Sedge	2.0	SGW003P	Graminoids/Forb	Field Mint	0.5
WSM015P	Graminoids/Forb	Aquatic Sedge	2.0	SGW004P	Graminoids/Forb	Field Mint	0.5
WSW017P	Graminoids/Forb	Aquatic Sedge	1.0	SGW006P	Graminoids/Forb	Field Mint	0.5
WSW018P	Graminoids/Forb	Aquatic Sedge	2.0	SGW011P	Graminoids/Forb	Field Mint	0.5
WSN020P	Graminoids/Forb	Aquatic Sedge	1.5	SGW013P	Graminoids/Forb	Field Mint	0.5
WSM022P	Graminoids/Forb	Aquatic Sedge	2.0	LPW057P	Graminoids/Forb	Field Mint	1.0
WSN400P	Graminoids/Forb	Aquatic Sedge	3.0	LPW058P	Graminoids/Forb	Field Mint	0.5
LPN049P	Graminoids/Forb	Aquatic Sedge	2.0	PPM064P	Graminoids/Forb	Field Mint	1.0
LPW050P	Graminoids/Forb	Aquatic Sedge	2.0	ARM026P	Graminoids/Forb	Foul Mannagrass	2.0
LPW052P	Graminoids/Forb	Aquatic Sedge	2.0	ARN028P	Graminoids/Forb	Foul Mannagrass	3.0
LPM053P	Graminoids/Forb	Aquatic Sedge	1.5	ARN029P	Graminoids/Forb	Foul Mannagrass	2.5
LPN056P	Graminoids/Forb	Aquatic Sedge	2.0	SGN007P	Graminoids/Forb	Inflated Sedge	1.0
LPM061P	Graminoids/Forb	Aquatic Sedge	2.0	SGW010P	Graminoids/Forb	Inflated Sedge	2.0
PPM068P	Graminoids/Forb	Aquatic Sedge	1.5	SGW011P	Graminoids/Forb	Inflated Sedge	2.0
SGM012P	Graminoids/Forb	Argrostis Spp	1.0	SGW013P	Graminoids/Forb	Inflated Sedge	2.0
SGW002P	Graminoids/Forb	Baltic Rush	1.5	WSM022P	Graminoids/Forb	Inflated Sedge	2.0
SGM012P	Graminoids/Forb	Baltic Rush	1.0	LPN055P	Graminoids/Forb	Inflated Sedge	2.0
SGW013P	Graminoids/Forb	Baltic Rush	1.5	LPW058P	Graminoids/Forb	Inflated Sedge	2.0
WSN016P	Graminoids/Forb	Baltic Rush	2.0	PPM062P	Graminoids/Forb	Inflated Sedge	1.5
LPW051P	Graminoids/Forb	Baltic Rush	2.0	SGW001P	Graminoids/Forb	Kentucky Bluegrass	2.0
LPW050P	Graminoids/Forb	Baltic Rush	2.0	SGN000P	Graminoids/Forb	Kentucky Bluegrass	2.0
PPM067P	Graminoids/Forb	Baltic Rush	2.0	SGW002P	Graminoids/Forb	Kentucky Bluegrass	2.0
SGW001P	Graminoids/Forb	Beaked Sedge	3.0	SGW003P	Graminoids/Forb	Kentucky Bluegrass	2.0
SGN000P	Graminoids/Forb	Beaked Sedge	3.0	SGW004P	Graminoids/Forb	Kentucky Bluegrass	2.0
SGW002P	Graminoids/Forb	Beaked Sedge	3.0	SGW005P	Graminoids/Forb	Kentucky Bluegrass	2.0
SGW003P	Graminoids/Forb	Beaked Sedge	3.0	SGW006P	Graminoids/Forb	Kentucky Bluegrass	2.0
SGW004P	Graminoids/Forb	Beaked Sedge	3.0	SGM012P	Graminoids/Forb	Kentucky Bluegrass	1.5
SGW006P	Graminoids/Forb	Beaked Sedge	3.0	SGM400P	Graminoids/Forb	Kentucky Bluegrass	1.5
CAN100P	Graminoids/Forb	Beaked Sedge	3.0	WSN014P	Graminoids/Forb	Kentucky Bluegrass	2.0
ARW030P	Graminoids/Forb	Bed Straw	2.0	WSM015P	Graminoids/Forb	Kentucky Bluegrass	1.5
ARM401P	Graminoids/Forb	Big Deer Vetch	3.0	WSN020P	Graminoids/Forb	Kentucky Bluegrass	1.5
WSW019P	Graminoids/Forb	Blue Wild Rye	3.0	WSM022P	Graminoids/Forb	Kentucky Bluegrass	2.0
ARM026P	Graminoids/Forb	Blue Wild Rye	2.5	WSW023P	Graminoids/Forb	Kentucky Bluegrass	2.0
ARN028P	Graminoids/Forb	Blue Wild Rye	2.5	ARW030P	Graminoids/Forb	Kentucky Bluegrass	1.5
ARW027P	Graminoids/Forb	Blue Wild Rye	2.0	LPN049P	Graminoids/Forb	Kentucky Bluegrass	2.0
ARN029P	Graminoids/Forb	Blue Wild Rye	3.0	LPW050P	Graminoids/Forb	Kentucky Bluegrass	2.0
ARW030P	Graminoids/Forb	Blue Wild Rye	5.0	LPM053P	Graminoids/Forb	Kentucky Bluegrass	1.0
ARW031P	Graminoids/Forb	Blue Wild Rye	2.5	LPM059P	Graminoids/Forb	Kentucky Bluegrass	2.0
LPN055P	Graminoids/Forb	Blue Wild Rye	2.5	PPN065P	Graminoids/Forb	Kentucky Bluegrass	2.0
LPN056P	Graminoids/Forb	Blue Wild Rye	2.5	PPM068P	Graminoids/Forb	Kentucky Bluegrass	2.0
LPM059P	Graminoids/Forb	Blue Wild Rye	2.5	PPN069P	Graminoids/Forb	Kentucky Bluegrass	2.0
LPM061P	Graminoids/Forb	Blue Wild Rye	3.0	WSW025P	Graminoids/Forb	Knot Weed	0.3
PPM064P	Graminoids/Forb	Blue Wild Rye	2.5	ARW030P	Graminoids/Forb	Lance Leaved Figwort	3.0
PPN065P	Graminoids/Forb	Blue Wild Rye	2.5	WSN020P	Graminoids/Forb	Large Leaved Avens	1.0
PPM067P	Graminoids/Forb	Blue Wild Rye	3.0	WSM022P	Graminoids/Forb	Large Leaved Avens	1.5
LPN055P	Graminoids/Forb	Bog Orchid	1.0	LPW050P	Graminoids/Forb	Large Leaved Avens	2.5
LPW050P	Graminoids/Forb	Broad Leaf Strawberry	0.3	LPN054P	Graminoids/Forb	Large Leaved Avens	2.0
LPM053P	Graminoids/Forb	Broad Leaf Strawberry	0.3	PPM063P	Graminoids/Forb	Large Leaved Avens	1.5
LPM059P	Graminoids/Forb	Broad Leaf Strawberry	0.3	WSM015P	Graminoids/Forb	Leafy Bract Aster	1.0
LPM061P	Graminoids/Forb	Broad Leaf Strawberry	0.3	WSW017P	Graminoids/Forb	Leafy Bract Aster	1.0
PPM067P	Graminoids/Forb	Broad Leaf Strawberry	0.3	WSW018P	Graminoids/Forb	Leafy Bract Aster	2.0
WSM015P	Graminoids/Forb	California Brome	2.0	WSW019P	Graminoids/Forb	Leafy Bract Aster	3.0
ARW030P	Graminoids/Forb	California Brome	4.0	WSM022P	Graminoids/Forb	Leafy Bract Aster	1.0
ARM401P	Graminoids/Forb	California Brome	3.5	LPN049P	Graminoids/Forb	Leafy Bract Aster	1.0
LPN054P	Graminoids/Forb	California Brome	2.5	LPN056P	Graminoids/Forb	Leafy Bract Aster	1.0
PPM062P	Graminoids/Forb	California Brome	2.0	PPM062P	Graminoids/Forb	Leafy Bract Aster	1.5
ARN028P	Graminoids/Forb	California False Hellebore	2.5	LPM059P	Graminoids/Forb	Long Stalked Clover	0.5
LPM059P	Graminoids/Forb	California False Hellebore	2.0	PPM067P	Graminoids/Forb	Long Stalked Clover	0.3
WSW018P	Graminoids/Forb	Canadian Goldenrod	1.5	PPM068P	Graminoids/Forb	Long Stalked Clover	0.5
WSW019P	Graminoids/Forb	Canadian Goldenrod	2.0	LPN049P	Graminoids/Forb	Lupine	2.0
WSW023P	Graminoids/Forb	Canadian Goldenrod	3.0	SGW001P	Graminoids/Forb	Macoon's Buttercup	0.5

Table 3-4continued). USFS Land cover Data

USFS Site	Land cover Type	Land cover Name	Height (feet)	USFS Site	Land cover Type	Land cover Name	Height (feet)
SGW003P	Graminoids/Forb	Macoon's Buttercup	1.0	LPM053P	Graminoids/Forb	Seep Spring Monkey Flower	2.0
SGW004P	Graminoids/Forb	Macoon's Buttercup	1.0	PPN065P	Graminoids/Forb	Seep Spring Monkey Flower	1.0
CAN100P	Graminoids/Forb	Mannagrass	3.0	SGW006P	Graminoids/Forb	Seep Spring Monkey Flower	0.5
ARN028P	Graminoids/Forb	Many Leaved Lupine	3.0	PPN069P	Graminoids/Forb	Self Heal	0.5
LPN054P	Graminoids/Forb	Marsh Mairgold	1.0	CAN100P	Graminoids/Forb	Service Berry	1.0
SGW005P	Graminoids/Forb	Marsh Marigold	1.0	LPM059P	Graminoids/Forb	Sheep Fescue	2.5
WSW017P	Graminoids/Forb	Marsh Marigold	1.0	PPW325P	Graminoids/Forb	Sheep Fescue	1.0
LPW052P	Graminoids/Forb	Marsh Marigold	1.0	SGN000P	Graminoids/Forb	Slender Cinquifoil	1.0
LPN055P	Graminoids/Forb	Marsh Marigold	1.0	PPM067P	Graminoids/Forb	Slender Cinquifoil	1.0
LPN056P	Graminoids/Forb	Marsh Marigold	1.0	LPN056P	Graminoids/Forb	Slender Hair Grass	2.5
LPM061P	Graminoids/Forb	Marsh Marigold	1.0	WSW018P	Graminoids/Forb	Slender Hairgrass	2.5
WSN400P	Graminoids/Forb	Mary Leaved Lupine	3.0	SGM012P	Graminoids/Forb	Small Bed Straw	0.3
SGW010P	Graminoids/Forb	Meadow Arnica	1.0	WSW019P	Graminoids/Forb	Small Fruit Bull Rush	2.5
SGW011P	Graminoids/Forb	Meadow Arnica	1.0	ARN028P	Graminoids/Forb	Small Fruit Bull Rush	2.5
SGW013P	Graminoids/Forb	Meadow Arnica	1.5	ARN029P	Graminoids/Forb	Small Fruit Bull Rush	2.0
WSW023P	Graminoids/Forb	Meadow Arnica	1.5	ARW031P	Graminoids/Forb	Small Fruit Bull Rush	2.0
LPW051P	Graminoids/Forb	Meadow Arnica	1.0	ARM401P	Graminoids/Forb	Small Fruit Bull Rush	2.0
LPW057P	Graminoids/Forb	Meadow Arnica	1.5	LPN054P	Graminoids/Forb	Small Fruit Bull Rush	2.0
LPW058P	Graminoids/Forb	Meadow Arnica	1.0	PPM062P	Graminoids/Forb	Small Fruit Bull Rush	1.0
LPM061P	Graminoids/Forb	Meadow Arnica	1.0	PPW066P	Graminoids/Forb	Small Fruit Bull Rush	2.5
PPW325P	Graminoids/Forb	Meadow Arnica	1.0	CAN100P	Graminoids/Forb	Small Fruit Bull Rush	2.0
PPN069P	Graminoids/Forb	Meadow Arnica	1.0	LPN049P	Graminoids/Forb	Smooth Fireweed	2.0
WSW025P	Graminoids/Forb	Meadow Aster	1.0	PPW066P	Graminoids/Forb	Smooth Fireweed	1.5
SGW001P	Graminoids/Forb	Meadow Barley	2.0	SGW001P	Graminoids/Forb	Smooth Willow Herb	1.0
SGW006P	Graminoids/Forb	Meadow Barley	2.5	SGW003P	Graminoids/Forb	Smooth Willow Herb	1.0
WSN016P	Graminoids/Forb	Meadow Barley	2.0	SGW004P	Graminoids/Forb	Smooth Willow Herb	1.0
WSW017P	Graminoids/Forb	Meadow Barley	1.5	SGW006P	Graminoids/Forb	Smooth Willow Herb	1.0
WSN020P	Graminoids/Forb	Meadow Barley	1.5	WSN014P	Graminoids/Forb	Smooth Willow Herb	1.0
LPN049P	Graminoids/Forb	Meadow Barley	3.0	WSN016P	Graminoids/Forb	Smooth Willow Herb	1.0
PPW325P	Graminoids/Forb	Meadow Barley	2.0	PPN065P	Graminoids/Forb	Smooth Willow Herb	1.5
Sycan39	Graminoids/Forb	Meadow Barley	2.0	CAN100P	Graminoids/Forb	Starrry Solomon's Plume	1.0
PPM064P	Graminoids/Forb	Meadow Barley	2.0	ARW031P	Graminoids/Forb	Starry Solomon's Plume	1.0
SGW006P	Graminoids/Forb	Meadow Fontail	3.0	ARM401P	Graminoids/Forb	Starry Solomon's Plume	1.0
SGM400P	Graminoids/Forb	Meadow Foxtail	2.5	LPW050P	Graminoids/Forb	Starry Solomon's Plume	1.0
WSM015P	Graminoids/Forb	Meadow Foxtail	2.0	PPM063P	Graminoids/Forb	Starry Solomon's Plume	1.0
WSN020P	Graminoids/Forb	Meadow Foxtail	2.5	PPM064P	Graminoids/Forb	Starry Solomon's Plume	1.0
SGM012P	Graminoids/Forb	Meadow Montia	0.3	PPN065P	Graminoids/Forb	Starry Solomon's Plume	1.0
ARN029P	Graminoids/Forb	Monk's Hood	4.0	PPW066P	Graminoids/Forb	Starry Solomon's Plume	1.0
LPM059P	Graminoids/Forb	Mountain Sweet Sicly	2.0	ARW030P	Graminoids/Forb	Stinging Nettle	5.0
ARM401P	Graminoids/Forb	Mountain Valley Violet	0.5	SGW005P	Graminoids/Forb	Stream Bank Butterweed	1.0
SGW013P	Graminoids/Forb	Mugwort	2.0	WSW017P	Graminoids/Forb	Stream Bank Butterweed	1.5
WSW019P	Graminoids/Forb	Mugwort	3.0	PPN065P	Graminoids/Forb	Stream Bank Butterweed	1.0
WSW023P	Graminoids/Forb	Mugwort	3.0	WSM015P	Graminoids/Forb	Stream Bank Sencio	2.0
LPW057P	Graminoids/Forb	Mugwort	2.0	LPW052P	Graminoids/Forb	Streambank Butterweed	2.0
PPM062P	Graminoids/Forb	Mugwort	1.5	SGM400P	Graminoids/Forb	Streambank Buttonweed	1.0
PPW066P	Graminoids/Forb	Mugwort	3.0	LPW052P	Graminoids/Forb	Swamp Onion	2.0
SGN000P	Graminoids/Forb	Nebraska Sedge	3.0	ARN029P	Graminoids/Forb	Sweet Scented Bed Straw	1.0
WSN016P	Graminoids/Forb	Nebraska Sedge	1.5	ARW031P	Graminoids/Forb	Sweet Scented Bed Straw	1.0
PPN069P	Graminoids/Forb	Nebraska Sedge	2.5	SGM012P	Graminoids/Forb	Sweet Scented Bedstraw	0.5
SGW004P	Graminoids/Forb	Nettle Barley	1.5	WSN014P	Graminoids/Forb	Sweet Scented Bedstraw	1.0
SGN007P	Graminoids/Forb	Nevada Rush	1.0	LPN055P	Graminoids/Forb	Tall Managrass	2.5
LPW050P	Graminoids/Forb	Nevada Rush	1.0	LPN054P	Graminoids/Forb	Tall Mannagrass	4.0
LPM053P	Graminoids/Forb	Nevada Rush	1.0	LPN056P	Graminoids/Forb	Tall Mannagrass	3.0
LPW057P	Graminoids/Forb	Northern Bed Straw	1.5	ARN029P	Graminoids/Forb	Triangular Leaf Sencio	3.0
WSW017P	Graminoids/Forb	Northern Managrass	1.5	LPN056P	Graminoids/Forb	Triangular Leaf Sencio	2.0
LPW057P	Graminoids/Forb	Northern Mannagrass	2.0	ARN028P	Graminoids/Forb	Triangular Leaved Sencio	2.0
SGW011P	Graminoids/Forb	Oregon Checker Mallow	0.5	ARW027P	Graminoids/Forb	Triangular Leaved Sencio	3.0
WSN016P	Graminoids/Forb	Oregon Checker Mallow	1.0	SGW001P	Graminoids/Forb	Tufted Hairgrass	2.0
WSN020P	Graminoids/Forb	Oregon Checker Mallow	1.0	SGN000P	Graminoids/Forb	Tufted Hairgrass	3.0
LPN054P	Graminoids/Forb	Oregon Checker Mallow	1.0	SGW003P	Graminoids/Forb	Tufted Hairgrass	2.0
WSN020P	Graminoids/Forb	Oregon Yampah	2.0	SGW005P	Graminoids/Forb	Tufted Hairgrass	2.0
ARW030P	Graminoids/Forb	Ox Eye Daisey	3.0	SGW010P	Graminoids/Forb	Tufted Hairgrass	2.5
LPM053P	Graminoids/Forb	Ox Eye Daisy	2.0	SGW011P	Graminoids/Forb	Tufted Hairgrass	2.0
SGM400P	Graminoids/Forb	Pagrostis	1.5	SGW013P	Graminoids/Forb	Tufted Hairgrass	2.0
SGW002P	Graminoids/Forb	Pussy Toes	1.0	WSN014P	Graminoids/Forb	Tufted Hairgrass	2.0
SGW005P	Graminoids/Forb	Ranger Buttons	1.5	WSN016P	Graminoids/Forb	Tufted Hairgrass	1.0
LPW052P	Graminoids/Forb	Ranger Buttons	2.0	WSM022P	Graminoids/Forb	Tufted Hairgrass	2.0
LPN055P	Graminoids/Forb	Ranger Buttons	3.0	ARM026P	Graminoids/Forb	Small Fruit Bull Rush	2.0
ARM401P	Graminoids/Forb	Red Fescue	1.5	WSW023P	Graminoids/Forb	Tufted Hairgrass	2.0
PPM062P	Graminoids/Forb	Red Fireweed	3.0	WSN400P	Graminoids/Forb	Tufted Hairgrass	3.0
ARW031P	Graminoids/Forb	Richardson's Geranium	1.0	LPW051P	Graminoids/Forb	Tufted Hairgrass	2.5
PPN069P	Graminoids/Forb	Rigid Hedge Nettle	2.0	LPW052P	Graminoids/Forb	Tufted Hairgrass	2.0
CAN100P	Graminoids/Forb	Rigid Hedge Nettle	1.0	LPN054P	Graminoids/Forb	Tufted Hairgrass	2.5
WSN014P	Graminoids/Forb	Rigid Hedgenettle	2.0	LPW057P	Graminoids/Forb	Tufted Hairgrass	2.0
CAN100P	Graminoids/Forb	Rosey Twisted Stalk	2.0	LPW058P	Graminoids/Forb	Tufted Hairgrass	2.0
ARN029P	Graminoids/Forb	Rusty Sedge	2.0	LPM061P	Graminoids/Forb	Tufted Hairgrass	2.5
LPN055P	Graminoids/Forb	Rusty Sedge	2.0	PPM068P	Graminoids/Forb	Tufted Hairgrass	2.0
LPM061P	Graminoids/Forb	Rusty Sedge	2.0	ARM026P	Graminoids/Forb	Twisted Stalk	2.0
WSM015P	Graminoids/Forb	Scarlet Paintbrush	1.0	WSW025P	Graminoids/Forb	Water Bent Grass	4.0
WSW017P	Graminoids/Forb	Scarlet Paintbrush	1.5	ARM026P	Graminoids/Forb	Water Bent Grass	2.5
WSW018P	Graminoids/Forb	Scarlet Paintbrush	1.5	ARN028P	Graminoids/Forb	Water Bent Grass	3.0
SGW013P	Graminoids/Forb	Scouring Rush	0.5	LPW051P	Graminoids/Forb	Water Hemlock Parsnip	3.0
WSW019P	Graminoids/Forb	Scouring Rush	1.0	SGM012P	Graminoids/Forb	Watson's Willow Herb	1.5
WSW023P	Graminoids/Forb	Scouring Rush	0.5	ARW031P	Graminoids/Forb	Western Buttercup	1.0
PPM063P	Graminoids/Forb	Scouring Rush	1.0	PPM067P	Graminoids/Forb	Western Buttercup	1.0
PPM064P	Graminoids/Forb	Scouring Rush	2.0	SGM400P	Graminoids/Forb	Western Meadow Aster	1.0
SGW010P	Graminoids/Forb	Seep Spring Monkey Flower	1.0	SGN000P	Graminoids/Forb	Western Meadow Aster	1.0

Table 3-4(continued). USFS Land cover Data

USFS Site	Land cover Type	Land cover Name	Height (feet)
SGW002P	Graminoids/Forb	Western Meadow Aster	1.0
SGW010P	Graminoids/Forb	Western Meadow Aster	1.0
SGW011P	Graminoids/Forb	Western Meadow Aster	1.0
WSN016P	Graminoids/Forb	Western Meadow Aster	1.0
WSN020P	Graminoids/Forb	Western Meadow Aster	1.0
LPW051P	Graminoids/Forb	Western Meadow Aster	1.0
LPW058P	Graminoids/Forb	Western Meadow Aster	1.0
PPW325P	Graminoids/Forb	Western Meadow Aster	1.5
Sycan37	Graminoids/Forb	Western Meadow Aster	2.0
PPM068P	Graminoids/Forb	Western Meadow Aster	1.0
ARM026P	Graminoids/Forb	Western Meadow Rye	3.0
LPN049P	Graminoids/Forb	Western Meadow Rye	2.0
LPN054P	Graminoids/Forb	Western Meadow Rye	2.0
LPN056P	Graminoids/Forb	Western Meadow Rye	3.0
LPM061P	Graminoids/Forb	Western Meadow Rye	2.0
WSW025P	Graminoids/Forb	Western Mugwort	2.5
PPW325P	Graminoids/Forb	Western Mugwort	2.5
Sycan38	Graminoids/Forb	Western Mugwort	2.0
PPM063P	Graminoids/Forb	Western Mugwort	2.0
PPM064P	Graminoids/Forb	Western Mugwort	1.0
SGM400P	Graminoids/Forb	Western Polemonium	1.0
WSM015P	Graminoids/Forb	Western Polemonium	1.0
WSM022P	Graminoids/Forb	Western Polemonium	1.0
ARM026P	Graminoids/Forb	Western Polemonium	1.0
LPN055P	Graminoids/Forb	Western Polemonium	1.0
SGW011P	Graminoids/Forb	Wooly Sedge	2.0
WSW019P	Graminoids/Forb	Wooly Sedge	2.0
LPW057P	Graminoids/Forb	Wooly Sedge	1.5
LPW058P	Graminoids/Forb	Wooly Sedge	2.0
Sycan41	Graminoids/Forb	Wooly Sedge	2.0
PPM067P	Graminoids/Forb	Wooly Sedge	2.0
PPM068P	Graminoids/Forb	Wooly Sedge	1.5
PPN069P	Graminoids/Forb	Wooly Sedge	2.0
WSW025P	Graminoids/Forb	Yellow Cone	1.5
SGW011P	Graminoids/Forb	Western Meadow Aster	1.0
WSN016P	Graminoids/Forb	Western Meadow Aster	1.0
WSN020P	Graminoids/Forb	Western Meadow Aster	1.0
LPW051P	Graminoids/Forb	Western Meadow Aster	1.0
LPW058P	Graminoids/Forb	Western Meadow Aster	1.0
PPW325P	Graminoids/Forb	Western Meadow Aster	1.5
Sycan37	Graminoids/Forb	Western Meadow Aster	2.0
PPM068P	Graminoids/Forb	Western Meadow Aster	1.0
ARM026P	Graminoids/Forb	Western Meadow Rye	3.0
LPN049P	Graminoids/Forb	Western Meadow Rye	2.0
LPN054P	Graminoids/Forb	Western Meadow Rye	2.0
LPN056P	Graminoids/Forb	Western Meadow Rye	3.0
LPM061P	Graminoids/Forb	Western Meadow Rye	2.0
WSW025P	Graminoids/Forb	Western Mugwort	2.5
PPW325P	Graminoids/Forb	Western Mugwort	2.5
Sycan38	Graminoids/Forb	Western Mugwort	2.0
PPM063P	Graminoids/Forb	Western Mugwort	2.0
PPM064P	Graminoids/Forb	Western Mugwort	1.0
SGM400P	Graminoids/Forb	Western Polemonium	1.0
WSM015P	Graminoids/Forb	Western Polemonium	1.0
WSM022P	Graminoids/Forb	Western Polemonium	1.0
ARM026P	Graminoids/Forb	Western Polemonium	1.0
LPN055P	Graminoids/Forb	Western Polemonium	1.0
SGW011P	Graminoids/Forb	Wooly Sedge	2.0
WSW019P	Graminoids/Forb	Wooly Sedge	2.0
LPW057P	Graminoids/Forb	Wooly Sedge	1.5
LPW058P	Graminoids/Forb	Wooly Sedge	2.0
Sycan41	Graminoids/Forb	Wooly Sedge	2.0
PPM067P	Graminoids/Forb	Wooly Sedge	2.0
PPM068P	Graminoids/Forb	Wooly Sedge	1.5
PPN069P	Graminoids/Forb	Wooly Sedge	2.0
WSW025P	Graminoids/Forb	Yellow Cone	1.5
LPW057P	Dryland Shrub	Antelope Bitter Brush	2.0
LPW057P	Dryland Shrub	Antelope Bitter Brush	2.0
SGW006P	Dryland Shrub	Antelope Bitterbrush	3.0
SGW011P	Dryland Shrub	Antelope Bitterbrush	2.0
LPW058P	Dryland Shrub	Antelope Bitterbrush	2.0
PPN065P	Dryland Shrub	Antelope Bitterbrush	2.5
PPN069P	Dryland Shrub	Antelope Bitterbrush	2.0
SGW010P	Dryland Shrub	Big Sagebrush	2.0
PPN069P	Dryland Shrub	Big Sagebrush	2.5
LPW051P	Dryland Shrub	Bitterbrush	2.0
PPM068P	Dryland Shrub	Bitterbrush	3.0
WSM015P	Wetland Shrub	Bog Birch	4.0
WSN016P	Wetland Shrub	Bog Birch	7.0
WSN400P	Wetland Shrub	Douglas Water Hemlock	4.0
SGM012P	Wetland Shrub	Golden Currant	6.0
ARW030P	Wetland Shrub	Golden Currant	5.0
SGW001P	Dryland Shrub	Green Rabbit Brush	3.0
SGW002P	Dryland Shrub	Green Rabbit Brush	1.0

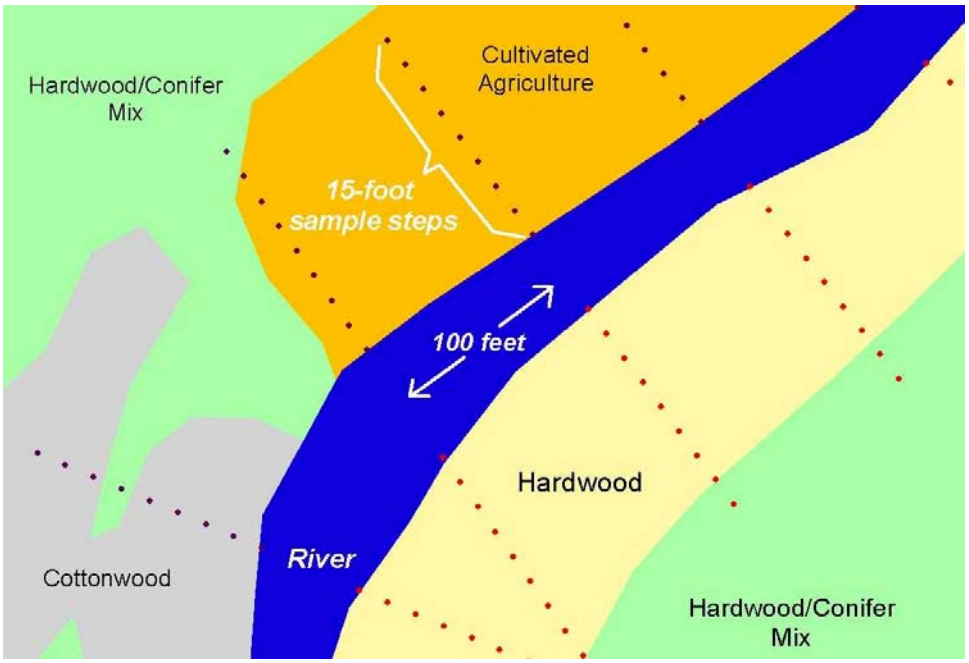
USFS Site	Land cover Type	Land cover Name	Height (feet)
LPW051P	Wetland Shrub	Caudata Willow	5.0
PPM062P	Dryland Shrub	Common Choke Cherry	8.0
PPW066P	Dryland Shrub	Common Choke Cherry	5.0
PPM067P	Dryland Shrub	Common Choke Cherry	4.0
ARW031P	Wetland Shrub	Common Snowberry	3.0
PPM063P	Wetland Shrub	Common Snowberry	4.0
PPM064P	Wetland Shrub	Common Snowberry	3.0
PPN065P	Wetland Shrub	Common Snowberry	2.5
PPW066P	Wetland Shrub	Common Snowberry	3.0
CAN100P	Wetland Shrub	Common Snowberry	3.0
ARW030P	Wetland Shrub	Douglas Spirea	3.0
ARW027P	Wetland Shrub	Douglas Spirea	4.0
ARW031P	Wetland Shrub	Douglas Spirea	4.0
LPW051P	Wetland Shrub	Douglas Spirea	2.5
LPW057P	Wetland Shrub	Douglas Spirea	3.0
LPW058P	Wetland Shrub	Douglas Spirea	4.0
LPM059P	Wetland Shrub	Douglas Spirea	2.5
PPW325P	Wetland Shrub	Douglas Spirea	4.0
Sycan34	Wetland Shrub	Douglas Spirea	4.0
PPM063P	Wetland Shrub	Douglas Spirea	5.0
PPM064P	Wetland Shrub	Douglas Spirea	3.0
PPM068P	Wetland Shrub	Douglas Spirea	4.0
PPN069P	Wetland Shrub	Douglas Spirea	2.5
SGW010P	Wetland Shrub	Douglas Spirea	2.0
SGW011P	Wetland Shrub	Douglas Spirea	2.0
SGW013P	Wetland Shrub	Douglas Spirea	2.0
WSN014P	Wetland Shrub	Douglas Spirea	2.5
WSN016P	Wetland Shrub	Douglas Spirea	3.0
WSW023P	Wetland Shrub	Douglas Spirea	4.0
ARM026P	Wetland Shrub	Douglas Spirea	3.0
SGW001P	Wetland Shrub	Geyers Willow	4.0
SGW002P	Wetland Shrub	Geyer's Willow	5.0
SGW003P	Wetland Shrub	Geyer's Willow	3.0
SGW005P	Wetland Shrub	Geyer's Willow	38.0
SGN007P	Wetland Shrub	Geyer's Willow	2.0
SGN009P	Wetland Shrub	Geyer's Willow	2.0
SGW010P	Wetland Shrub	Geyer's Willow	5.0
SGW011P	Wetland Shrub	Geyer's Willow	3.0
SGM012P	Wetland Shrub	Geyer's Willow	6.0
SGW013P	Wetland Shrub	Geyer's Willow	4.0
SGM400P	Wetland Shrub	Geyer's Willow	6.0
WSN014P	Wetland Shrub	Geyer's Willow	10.0
WSM015P	Wetland Shrub	Geyer's Willow	6.0
WSN016P	Wetland Shrub	Geyer's Willow	9.0
WSW017P	Wetland Shrub	Geyer's Willow	12.0
WSW018P	Wetland Shrub	Geyer's Willow	7.0
WSN020P	Wetland Shrub	Geyer's Willow	10.0
WSM022P	Wetland Shrub	Geyer's Willow	9.0
WSN400P	Wetland Shrub	Geyer's Willow	13.0
WSW025P	Wetland Shrub	Geyer's Willow	15.0
LPW052P	Wetland Shrub	Geyer's Willow	1.0
LPM053P	Wetland Shrub	Geyer's Willow	6.0
LPN055P	Wetland Shrub	Geyer's Willow	3.0
LPW058P	Wetland Shrub	Geyer's Willow	4.0
PPM067P	Wetland Shrub	Geyer's Willow	6.0
PPM068P	Wetland Shrub	Geyer's Willow	2.0
ARW027P	Wetland Shrub	Klamath Plum	4.0
WSW018P	Wetland Shrub	Lemon's Willow	12.0
SGW013P	Wetland Shrub	Mountain Alder	2.0
WSN014P	Wetland Shrub	Mountain Alder	3.0
WSW018P	Wetland Shrub	Mountain Alder	12.0
WSW019P	Wetland Shrub	Mountain Alder	10.0
ARM026P	Wetland Shrub	Mountain Alder	15.0
ARN028P	Wetland Shrub	Mountain Alder	15.0
ARW027P	Wetland Shrub	Mountain Alder	16.0
ARN029P	Wetland Shrub	Mountain Alder	15.0
ARW030P	Wetland Shrub	Mountain Alder	15.0
ARW031P	Wetland Shrub	Mountain Alder	17.0
ARM401P	Wetland Shrub	Mountain Alder	16.0
LPN056P	Wetland Shrub	Mountain Alder	4.0
LPM059P	Wetland Shrub	Mountain Alder	5.0
LPM061P	Wetland Shrub	Mountain Alder	4.0
PPM064P	Wetland Shrub	Mountain Alder	12.0
PPN065P	Wetland Shrub	Mountain Alder	13.0
SGW006P	Wetland Shrub	Pacific Willow	4.0
SGW013P	Wetland Shrub	Pacific Willow	5.0
WSM015P	Wetland Shrub	Pacific Willow	5.0
WSW019P	Wetland Shrub	Pacific Willow	15.0
WSN020P	Wetland Shrub	Pacific Willow	6.0
WSM022P	Wetland Shrub	Pacific Willow	6.0
WSW023P	Wetland Shrub	Pacific Willow	7.0
WSW025P	Wetland Shrub	Pacific Willow	15.0
ARW027P	Wetland Shrub	Pacific Willow	6.0
ARM401P	Wetland Shrub	Pacific Willow	20.0
LPN049P	Wetland Shrub	Pacific Willow	10.0
LPW050P	Wetland Shrub	Pacific Willow	6.0

Table 3-4(continued). USFS Land cover Data

USFS Site	Land cover Type	Land cover Name	Height (feet)
LPN054P	Wetland Shrub	Pacific Willow	6.0
LPN056P	Wetland Shrub	Pacific Willow	3.0
LPW058P	Wetland Shrub	Pacific Willow	4.0
LPM059P	Wetland Shrub	Pacific Willow	4.0
LPM061P	Wetland Shrub	Pacific Willow	4.0
Sycan32	Wetland Shrub	Pacific Willow	5.0
PPM062P	Wetland Shrub	Pacific Willow	12.0
PPW066P	Wetland Shrub	Pacific Willow	14.0
PPM068P	Wetland Shrub	Pacific Willow	6.0
PPN069P	Wetland Shrub	Pacific Willow	8.0
WSW023P	Wetland Shrub	Red Osier Dogwood	6.0
PPW325P	Wetland Shrub	Red Osier Dogwood	6.0
Sycan33	Wetland Shrub	Red Osier Dogwood	7.0
PPM062P	Wetland Shrub	Red Osier Dogwood	6.0
ARW030P	Wetland Shrub	Red-Osier Dogwood	13.0
ARW031P	Wetland Shrub	Red-Osier Dogwood	6.0
LPM059P	Wetland Shrub	Red-Osier Dogwood	3.0
PPW066P	Wetland Shrub	Red-Osier Dogwood	5.0
PPW325P	Wetland Shrub	River Bank Willow	4.0
ARM026P	Wetland Shrub	Swamp Current	2.0
ARN028P	Wetland Shrub	Swamp Current	2.0
LPM060P	Wetland Shrub	Swamp Current	3.0
CAN100P	Wetland Shrub	Swamp Current	3.0
SGW002P	Wetland Shrub	Wax Currant	4.0
SGW003P	Wetland Shrub	Wax Currant	3.0
SGW004P	Wetland Shrub	Wax Currant	3.0
SGW006P	Wetland Shrub	Wax Currant	4.0
SGW011P	Wetland Shrub	Wax Currant	5.0
LPW050P	Wetland Shrub	Wax Currant	5.0
LPM053P	Wetland Shrub	Wax Currant	3.0
SGN000P	Wetland Shrub	Wax Current	3.0
WSN016P	Wetland Shrub	Wax Current	4.0
WSW023P	Dryland Shrub	Western Service Berry	6.0
ARN028P	Dryland Shrub	Western Service Berry	2.0
LPM053P	Dryland Shrub	Western Service Berry	5.0
LPW057P	Dryland Shrub	Western Service Berry	4.0
PPM062P	Dryland Shrub	Western Service Berry	4.0
PPM063P	Dryland Shrub	Western Service Berry	6.0
PPM067P	Dryland Shrub	Western Service Berry	3.0
CAN100P	Wetland Shrub	Willow	5.0
WSW018P	Wetland Shrub	Woods Rose	5.0
LPW057P	Wetland Shrub	Woods Rose	2.0
PPW325P	Wetland Shrub	Woods Rose	4.0
Sycan35	Wetland Shrub	Woods Rose	3.0
CAN100P	Tree-Conifer	Douglas Fir	70.0
CAN100P	Tree-Conifer	Incense Cedar	70.0
ARM401P	Tree-Conifer	Jeffry Pine	40.0
SGW001P	Tree-Conifer	Lodgepole Pine	60.0
SGN000P	Tree-Conifer	Lodgepole Pine	65.0
SGW002P	Tree-Conifer	Lodgepole Pine	60.0
SGW003P	Tree-Conifer	Lodgepole Pine	60.0
SGW004P	Tree-Conifer	Lodgepole Pine	60.0
SGW005P	Tree-Conifer	Lodgepole Pine	60.0
SGW006P	Tree-Conifer	Lodgepole Pine	60.0
SGN007P	Tree-Conifer	Lodgepole Pine	60.0
SGN009P	Tree-Conifer	Lodgepole Pine	80.0
SGW010P	Tree-Conifer	Lodgepole Pine	65.0
SGW011P	Tree-Conifer	Lodgepole Pine	65.0
SGM012P	Tree-Conifer	Lodgepole Pine	75.0
SGW013P	Tree-Conifer	Lodgepole Pine	60.0
SGM400P	Tree-Conifer	Lodgepole Pine	70.0
WSN014P	Tree-Conifer	Lodgepole Pine	60.0
WSM015P	Tree-Conifer	Lodgepole Pine	80.0
WSN016P	Tree-Conifer	Lodgepole Pine	70.0
WSW017P	Tree-Conifer	Lodgepole Pine	70.0
WSW018P	Tree-Conifer	Lodgepole Pine	60.0
WSN020P	Tree-Conifer	Lodgepole Pine	75.0
WSM022P	Tree-Conifer	Lodgepole Pine	50.0
WSN400P	Tree-Conifer	Lodgepole Pine	40.0
ARM026P	Tree-Conifer	Lodgepole Pine	60.0
ARN028P	Tree-Conifer	Lodgepole Pine	80.0
ARW027P	Tree-Conifer	Lodgepole Pine	80.0
ARN029P	Tree-Conifer	Lodgepole Pine	20.0
LPW051P	Tree-Conifer	Lodgepole Pine	70.0
LPW050P	Tree-Conifer	Lodgepole Pine	80.0
LPW052P	Tree-Conifer	Lodgepole Pine	70.0
LPM053P	Tree-Conifer	Lodgepole Pine	65.0
LPN054P	Tree-Conifer	Lodgepole Pine	70.0
LPN055P	Tree-Conifer	Lodgepole Pine	70.0
LPW057P	Tree-Conifer	Lodgepole Pine	70.0
LPW058P	Tree-Conifer	Lodgepole Pine	65.0
LPM059P	Tree-Conifer	Lodgepole Pine	75.0
LPM060P	Tree-Conifer	Lodgepole Pine	60.0
LPM061P	Tree-Conifer	Lodgepole Pine	60.0
LPN049P	Tree-Conifer	Lodgepole Pine	60.0
LPN056P	Tree-Conifer	Lodgepole Pine	70.0
SGW006P	Tree-Conifer	Ponderosa Pine	60.0
SGW010P	Tree-Conifer	Ponderosa Pine	70.0
SGW011P	Tree-Conifer	Ponderosa Pine	80.0
SGM012P	Tree-Conifer	Ponderosa Pine	65.0
SGW013P	Tree-Conifer	Ponderosa Pine	70.0
WSN016P	Tree-Conifer	Ponderosa Pine	65.0
WSW019P	Tree-Conifer	Ponderosa Pine	65.0
WSW023P	Tree-Conifer	Ponderosa Pine	100.0
WSW025P	Tree-Conifer	Ponderosa Pine	70.0
ARW027P	Tree-Conifer	Ponderosa Pine	90.0
ARW030P	Tree-Conifer	Ponderosa Pine	80.0
ARW031P	Tree-Conifer	Ponderosa Pine	100.0
ARM401P	Tree-Conifer	Ponderosa Pine	40.0
LPN049P	Tree-Conifer	Ponderosa Pine	60.0
LPW051P	Tree-Conifer	Ponderosa Pine	80.0
LPW050P	Tree-Conifer	Ponderosa Pine	65.0
LPM053P	Tree-Conifer	Ponderosa Pine	65.0
LPW057P	Tree-Conifer	Ponderosa Pine	80.0
LPW058P	Tree-Conifer	Ponderosa Pine	80.0
Sycan31	Tree-Conifer	Ponderosa pine	80.0
PPM062P	Tree-Conifer	Ponderosa Pine	70.0
PPM063P	Tree-Conifer	Ponderosa Pine	80.0
PPM064P	Tree-Conifer	Ponderosa Pine	65.0
PPN065P	Tree-Conifer	Ponderosa Pine	20.0
PPW066P	Tree-Conifer	Ponderosa Pine	70.0
PPM067P	Tree-Conifer	Ponderosa Pine	70.0
PPM068P	Tree-Conifer	Ponderosa Pine	75.0
PPN069P	Tree-Conifer	Ponderosa Pine	65.0
PPW325P	Tree-Conifer	Ponderosa Pine	80.0
ARN028P	Tree-Conifer	White Fir	85.0
PPM067P	Tree-Conifer	White Fir	15.0
SGW013P	Tree-Conifer	Western Juniper	18.0
ARW030P	Tree-Conifer	Western Juniper	40.0
ARM401P	Tree-Conifer	Western Juniper	7.0
LPM053P	Tree-Conifer	Western Juniper	15.0
LPW057P	Tree-Conifer	Western Juniper	15.0
PPM062P	Tree-Conifer	Western Juniper	18.0
PPM067P	Tree-Conifer	Western Juniper	10.0
PPM068P	Tree-Conifer	Western Juniper	25.0
PPN069P	Tree-Conifer	Western Juniper	10.0
PPN069P	Tree-Deciduous	Quaking Aspen	45.0
PPM062P	Tree-Deciduous	Black Cottonwood	8.0
CAN100P	Tree-Deciduous	Black Cottonwood	70.0

Using classifications listed in **Table 3-3,** near stream land cover and land cover mapping and sampling can be completed across a large landscape scale. Summarized land cover attributes (e.g. height, density and overhang data) are used to populate the digitized land cover polygons. Automated sampling can then be conducted at user defined longitudinal and transverse intervals. Mainstem rivers and selected major tributaries are typically the focus.

The digitized/classified riparian land cover layer is sampled using Ttools. The **Figure 3-17** illustrates how Ttools samples riparian land cover. For every stream data node (i.e. every 100 feet along the stream channel centerline), beginning at the edge of the stream channel, sampling occurs perpendicular to the stream at eight user-defined intervals (i.e. every 15 feet). This sampling occurs for both stream banks for every stream data node.



***Land cover sampling** is performed at each data node and extends in the transverse direction at a user-defined interval (the default is every 15 feet). The user also has the option of sampling starting at the stream node or outside of the channel edge.*

***Figure 3-17**. Automated sampling of near stream land cover data using Ttools.*

3.5.3 Near Stream Land Cover - Potential Condition Development

The process of developing potential near stream land cover data should start with definitions and a discussion of the context in which it is used in the TMDL methodology. **Potential near stream land cover** is that which can grow and reproduce on a site given plant biology, site elevation, soil characteristics and local climate. Potential near stream land cover does not include considerations for resource management, human use or other human disturbance. Natural disturbance regimes (i.e. fire, disease, wind-throw, etc.) are also not accounted for in this definition. There is an assumption that despite natural disturbance, potential near stream land cover types (as defined) will survive and recover from a natural disturbance event.

The TMDL methodology is developed under the Oregon stream temperature standard where a condition of "no anthropogenic warming" is allowed. In simple terms, a condition is targeted where human related stream warming is minimized. Since near stream land cover is a controlling factor in stream temperature regimes, the condition and health of land cover is considered a primary parameter considered in the TMDL. Removal of human disturbance from near stream

land cover is a pathway for compliance with Oregon's stream temperature standard. **Potential near stream land cover**, by definition, is the condition that meets Oregon's stream temperature standard, and is therefore, targeted in the TMDL

Developing land cover potentials can often be complex. ODEQ has attempted to simplify the procedure for developing potential land cover data sets with simple rules based upon clearly stated assumptions. And, ODEQ acknowledges that in some areas the potential land cover type/distribution is not a well understood science. This is particularly true for low gradient meadow systems that have been subject to the removal of woody shrubs such as willows. Literature and local expertise from the Klamath Tribes, federal and state agencies do not always agree on the land cover potential of a given site. ODEQ acknowledges these uncertainties. A range of land cover types/attributes is used in the TMDL where land cover potential is not documented in the literature, evident in ground level studies/data or provided by the professional judgment of local experts in the Upper Klamath Lake drainage and surrounding areas. The Upper Klamath Lake drainage has numerous low gradient meadows that are largely occupied by cultivated agriculture, pastures or upland/wetland grasses. The extent that these meadows can support wetland and upland shrubs is not well documented. Therefore, ODEQ has developed a high and low probability distribution for these areas. Using a random number routine, both 75% and a 25% probability distributions were developed to simulate the range of shrub potential land cover types. The same random number routine was used to develop the graphic below.

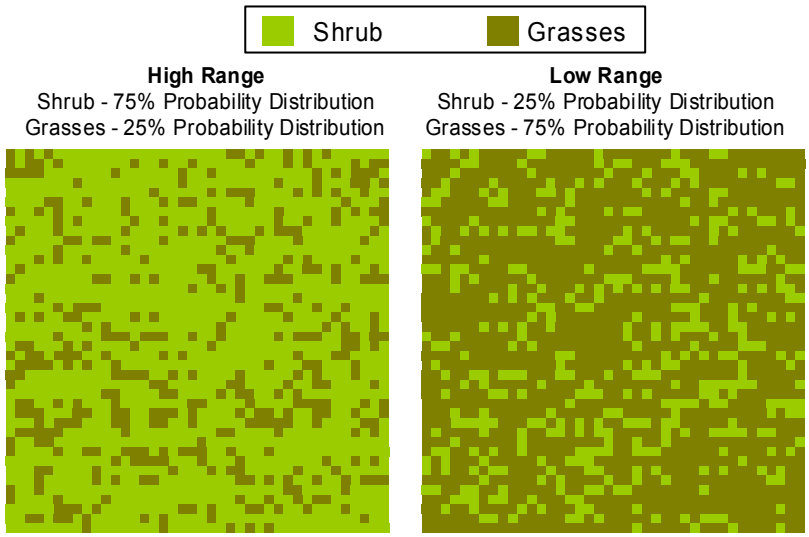


Figure 3-18. *Probability Distributions for Potential Shrub Land Cover Types*

Rules for Developing Potential Near Stream Land Cover

1. Barren land cover types that can grow land cover (i.e. clearcut areas, embankments, forest roads, etc.) are assigned the nearest adjacent non-developed land cover type.
2. Developed land cover types that can grow land cover are assigned the nearest adjacent non-developed land cover type.
3. Pastures, cultivated fields and lawn land cover types are assigned the nearest adjacent non-developed land cover type.
4. Instream and channel structures (i.e. dikes, canals, etc.) land cover types that can grow land cover are assigned the nearest adjacent non-developed land cover type.
5. Water and barren rock cannot grow land cover and are not changed.
6. The Klamath Marsh land cover type is not changed due to lack of information regarding potential land cover types/attributes.
7. The Western Juniper land cover type is not changed due to lack of information regarding potential land cover types/attributes.
8. The large conifer land cover type is considered at potential and land cover type/attributes are not changed.
9. The large hardwood land cover type is considered at potential and land cover type/attributes are not changed.
10. The large mixed conifer/hardwood land cover type is considered at potential and land cover type/attributes are not changed.
11. The upland shrub land cover type is considered at potential and land cover type/attributes are not changed.
12. The wetland shrub land cover type is considered at potential and land cover type/attributes are not changed.
13. The small conifer land cover type is assumed to grow to the large conifer land cover type/attributes.
14. The small hardwood land cover type is assumed to grow to the large hardwood land cover type/attributes.
15. The small mixed conifer/hardwood land cover type is assumed to grow to the large mixed conifer/hardwood land cover type/attributes.
16. In the high range, the upland grasses land cover type is assumed to grow upland shrub land cover type/attributes at a 75% probability distribution and upland grasses land cover type/attributes at a 25% probability distribution.
17. In the high range, the wetland grasses land cover type is assumed to grow wetland shrub land cover type/attributes at a 75% probability distribution and wetland grasses land cover type/attributes at a 25% probability distribution.
18. In the low range, the upland grasses land cover type is assumed to grow upland shrub land cover type/attributes at a 25% probability distribution and upland grasses land cover type/attributes at a 75% probability distribution.
19. In the low range, the wetland grasses land cover type is assumed to grow wetland shrub land cover type/attributes at a 25% probability distribution and wetland grasses land cover type/attributes at a 75% probability distribution.
20. Land cover density for each land cover type remains unchanged between current and potential conditions.

Table 3-5. ODEQ Land Cover Classifications for Digitized Polygons

Code	Land Cover Description	Potential Land Cover
301	Water	No Change
302	Pastures/Cultivated Field/lawn	Adjacent Non-Developed Land Cover
304	Barren – Rock	No Change
305	Barren – Embankment	Adjacent Non-Developed Land Cover
308	Barren – Clearcut	Adjacent Non-Developed Land Cover
309	Barren - Soil	Adjacent Non-Developed Land Cover
400	Barren – Road	Adjacent Non-Developed Land Cover
401	Barren - Forest Road	Adjacent Non-Developed Land Cover
500	Large Mixed Conifer/Hardwood	No Change
501	Small Mixed Conifer/Hardwood	Large Mixed Conifer/Hardwood
550	Large Mixed Conifer/Hardwood	No Change
551	Small Mixed Conifer/Hardwood	Large Mixed Conifer/Hardwood
555	Large Mixed Conifer/Hardwood	No Change
600	Large Hardwood	No Change
601	Small Hardwood	Large Hardwood
650	Large Hardwood	No Change
651	Small Hardwood	Large Hardwood
655	Large Hardwood	No Change
700	Large Conifer	No Change
701	Small Conifer	Large Conifer
750	Large Conifer	No Change
751	Small Conifer	Large Conifer
755	Western Juniper	No Change
800	Upland shrubs	No Change
850	Upland Shrubs	No Change
801	Shrubs on wet floodplain	No Change
851	Shrubs on wet floodplain	No Change
900	Grasses - upland	High Range - 75% Distribution of Upland Shrub (800) Low Range - 25% Distribution of Upland Shrub (800)
901/902	Grasses - saturated	High Range - 75% Distribution of Wetland Shrub (801) Low Range - 25% Distribution of Wetland Shrub (801)
3011	Active Channel Bottom	No Change
3248	Development - Residential	Adjacent Non-Developed Land Cover
3249	Development - Industrial	Adjacent Non-Developed Land Cover
3252	Dam/Weir	Adjacent Non-Developed Land Cover
3255	Canal	Adjacent Non-Developed Land Cover
3256	Dike	Adjacent Non-Developed Land Cover
1	Klamath Marsh Area	No Change

3.5.4 Results - 2-Deminsional Near Stream Land Cover Height

Land cover was sampled for the Williamson River, Sprague River, South and North Forks Sprague River, Sycan River, Fishhole Creek and Trout Creek. The current condition and developed potential near stream land cover condition (both high and low ranges) are plotted in **Figures 3-19** to **3-29**.

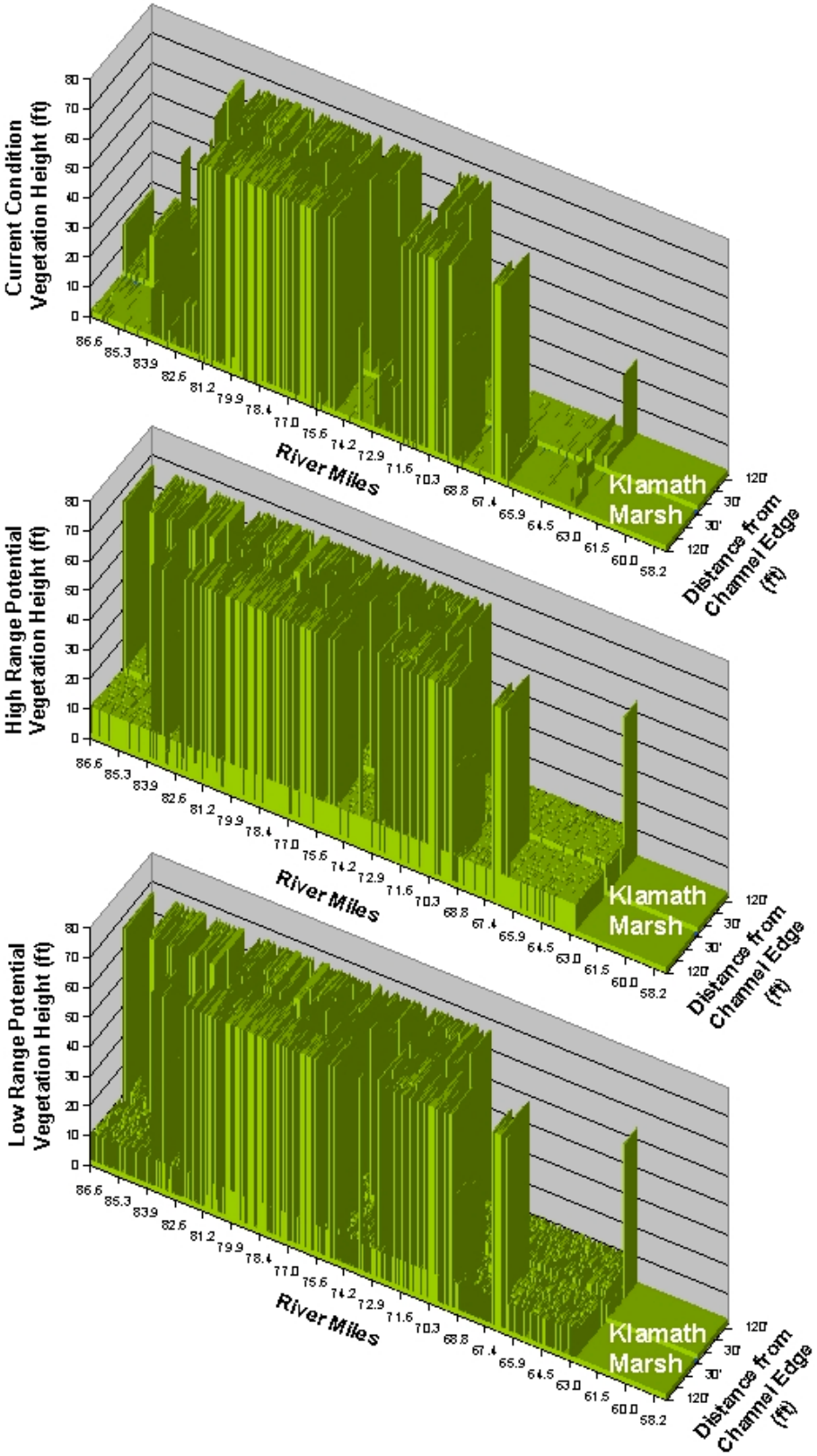


Figure 3-19. Williamson River Near Stream Land cover Height - River Miles 57.7 to 86.6

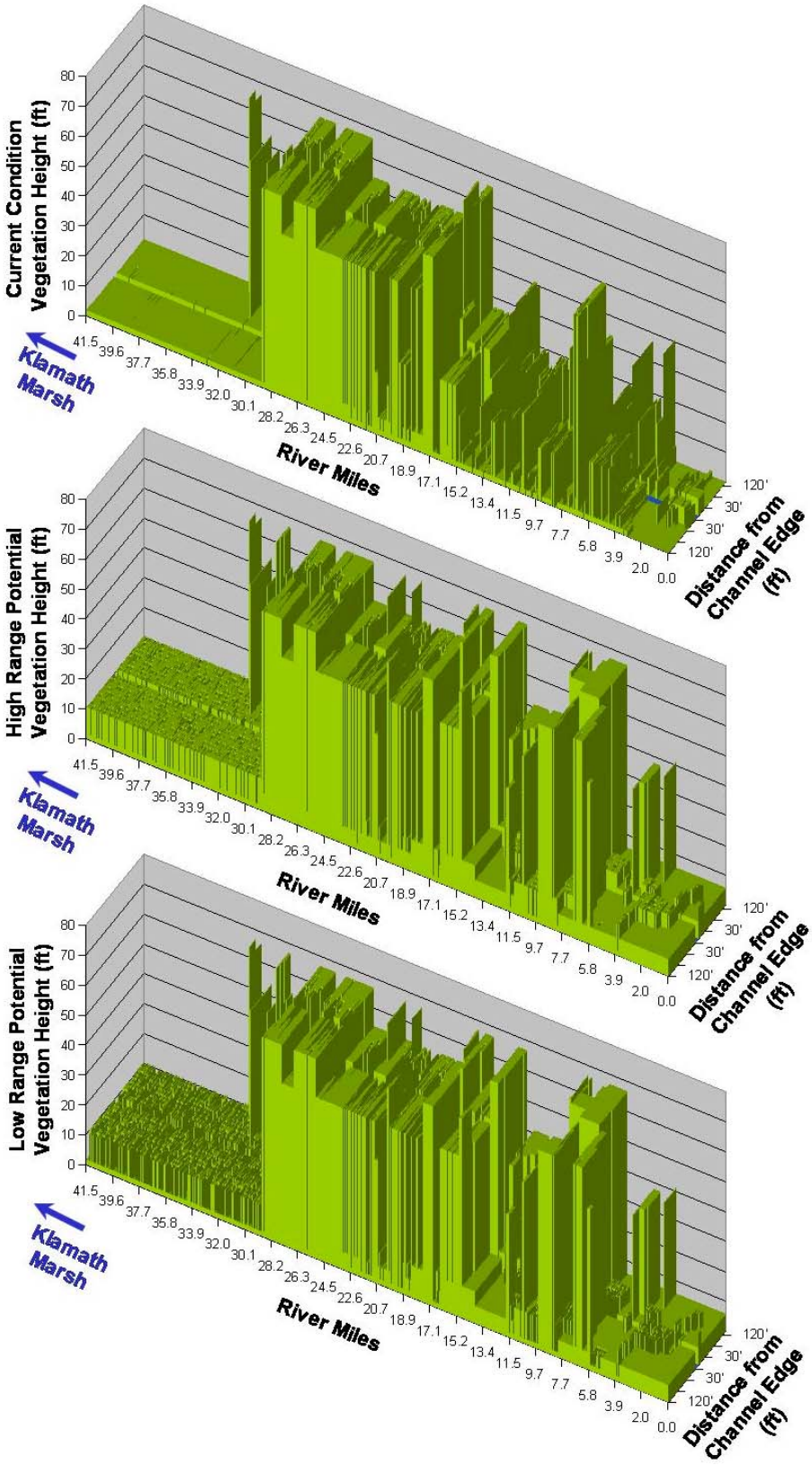


Figure 3-20. Williamson River Near Stream Land cover Height - River Miles 0.0 to 41.5

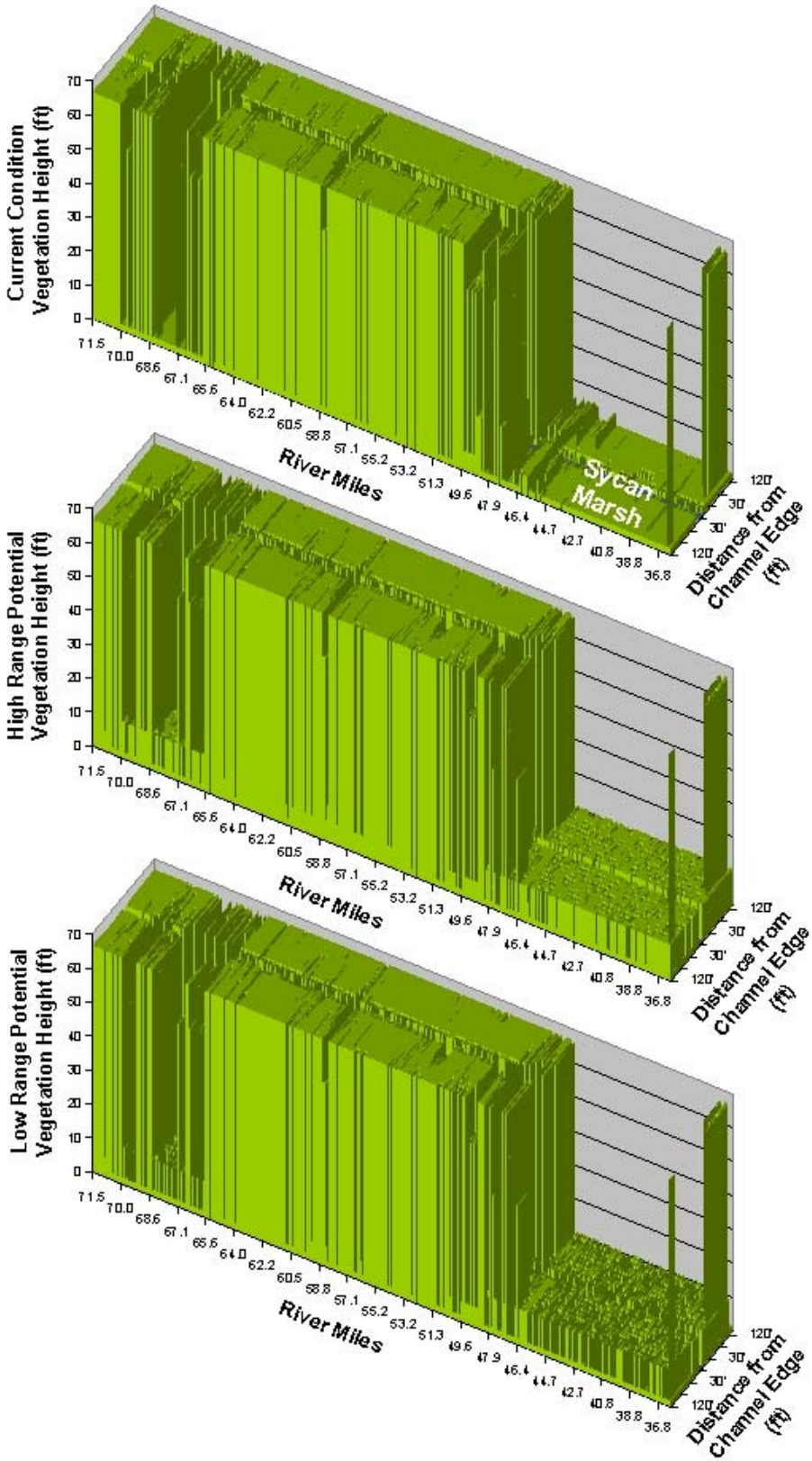


Figure 3-21. Sycan River Near Stream Land cover Height - River Miles 36.0 to 71.5

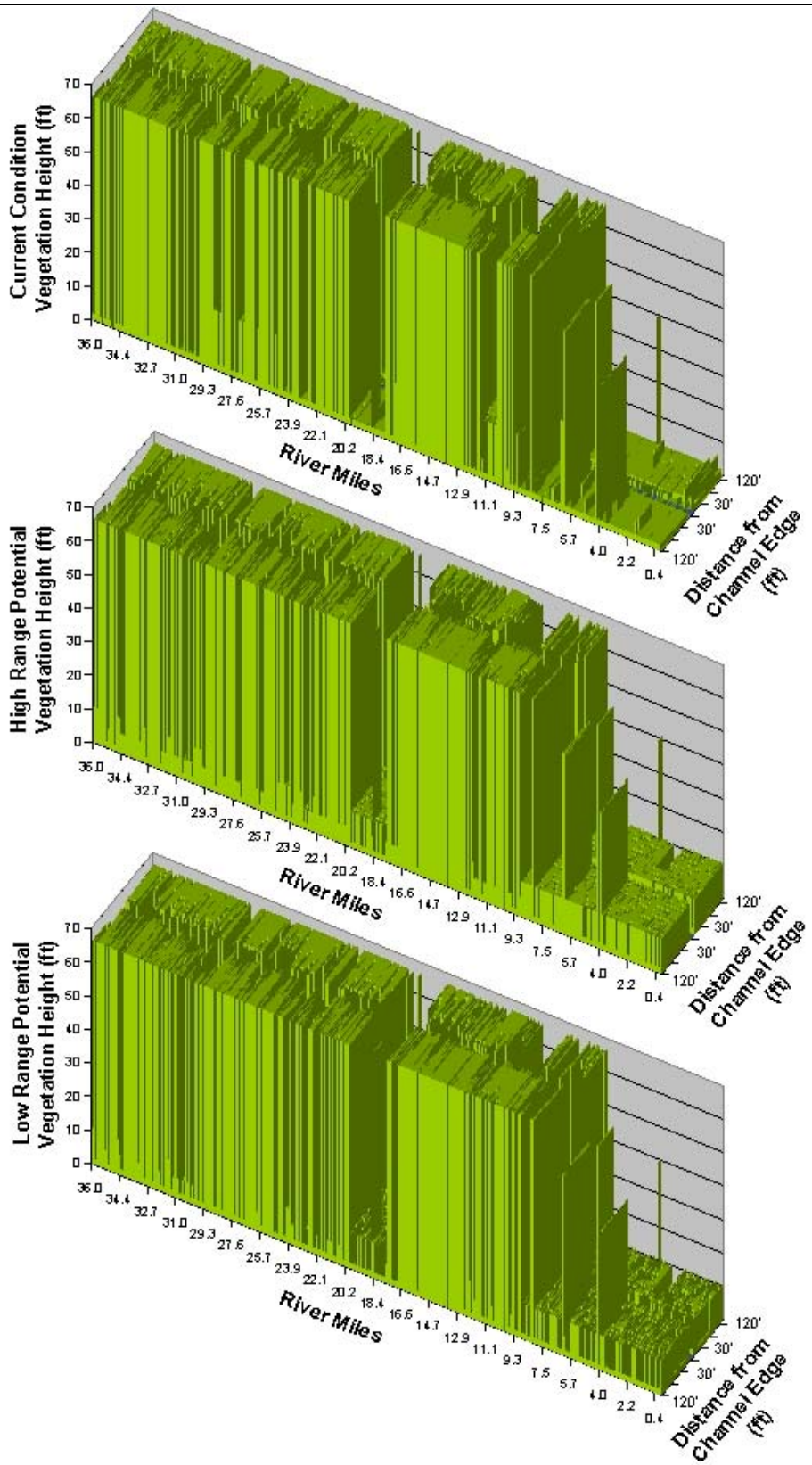


Figure 3-22. Sycan River Near Stream Land cover Height - River Miles 0.0 to 36.0

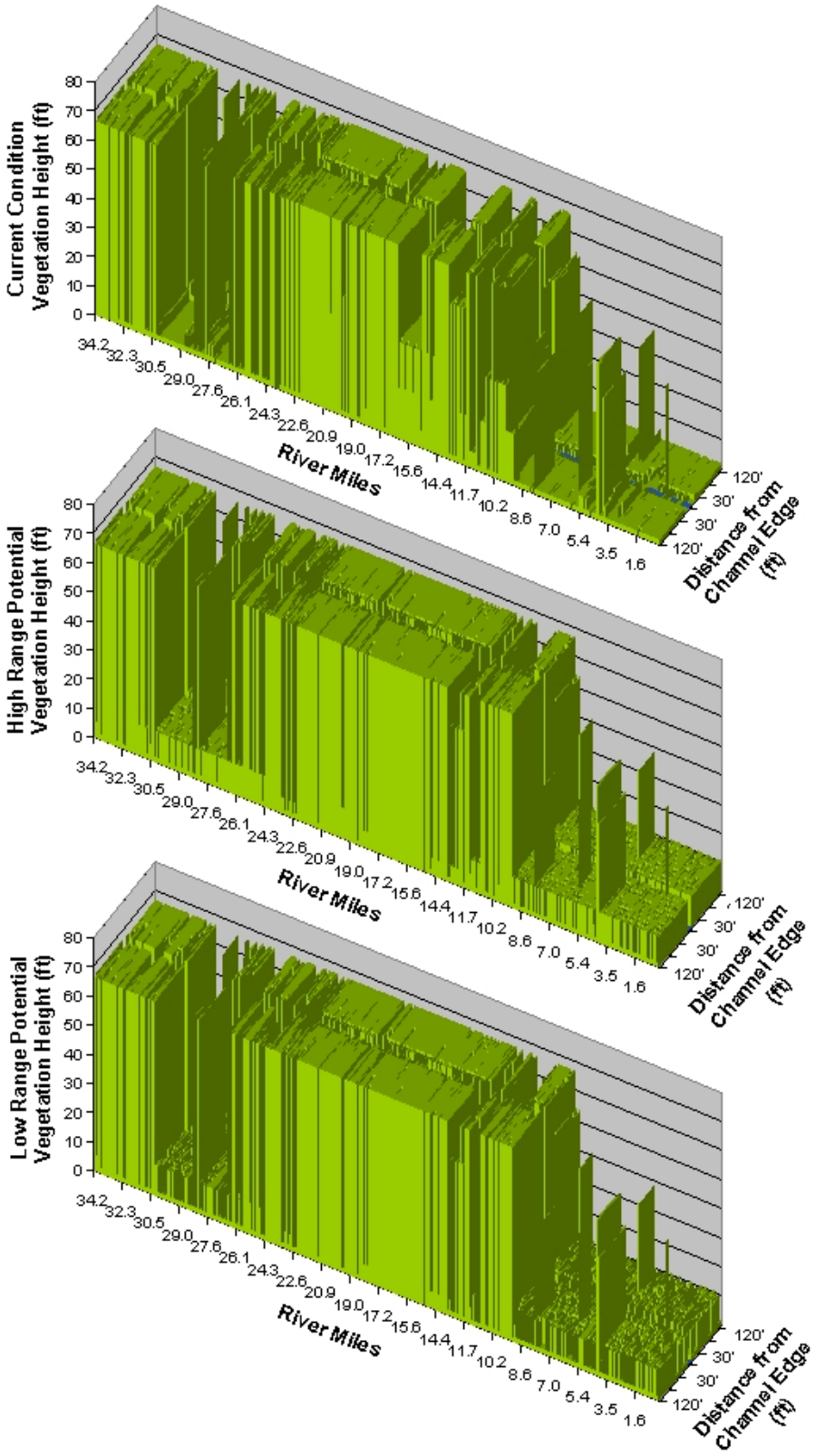


Figure 3-23. North Fork Sprague River Near Stream Land cover Height - River Miles 0.0 to 34.2

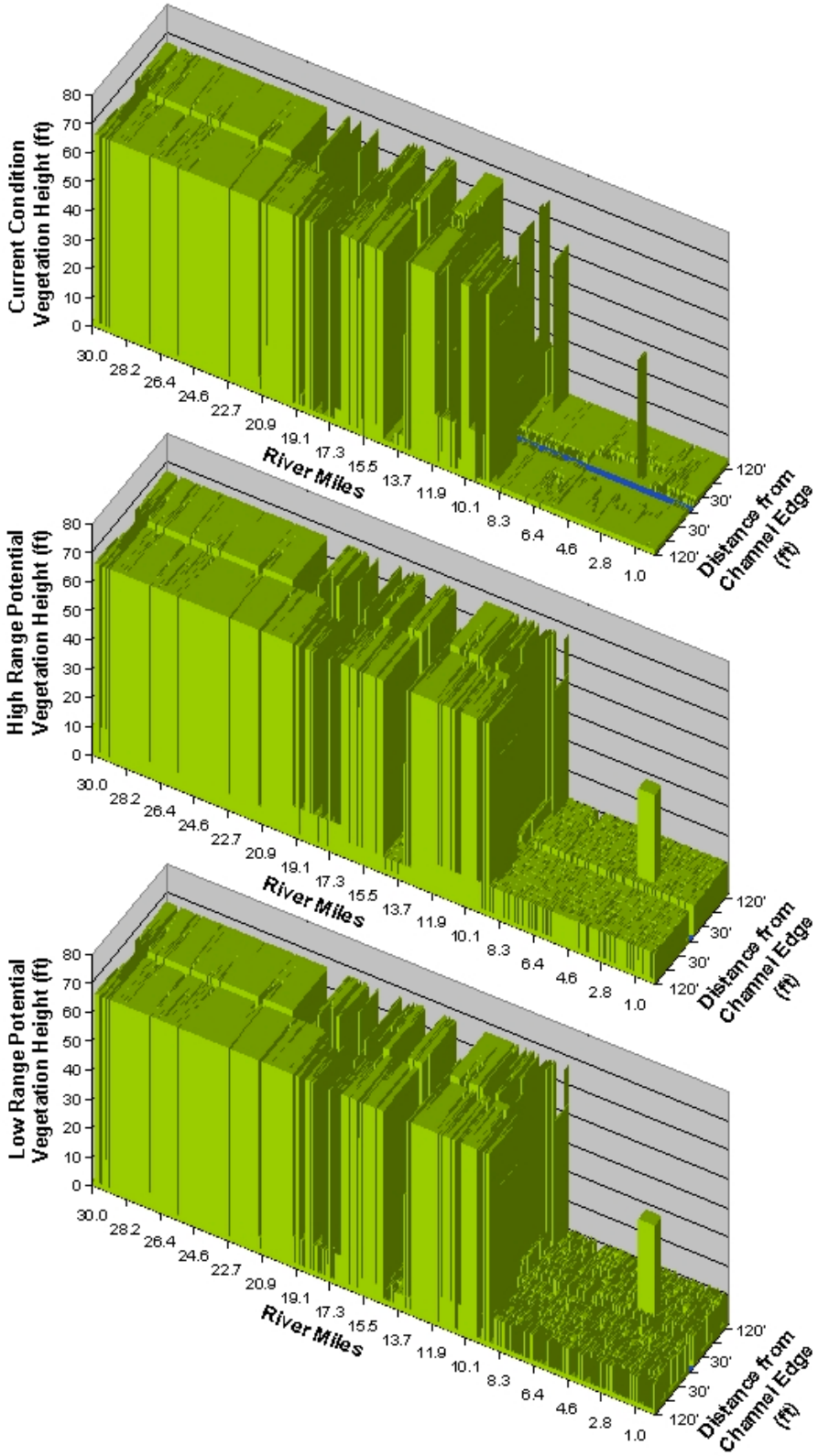


Figure 3-24. South Fork Sprague River Near Stream Land cover Height - River Miles 0.0 to 30.0

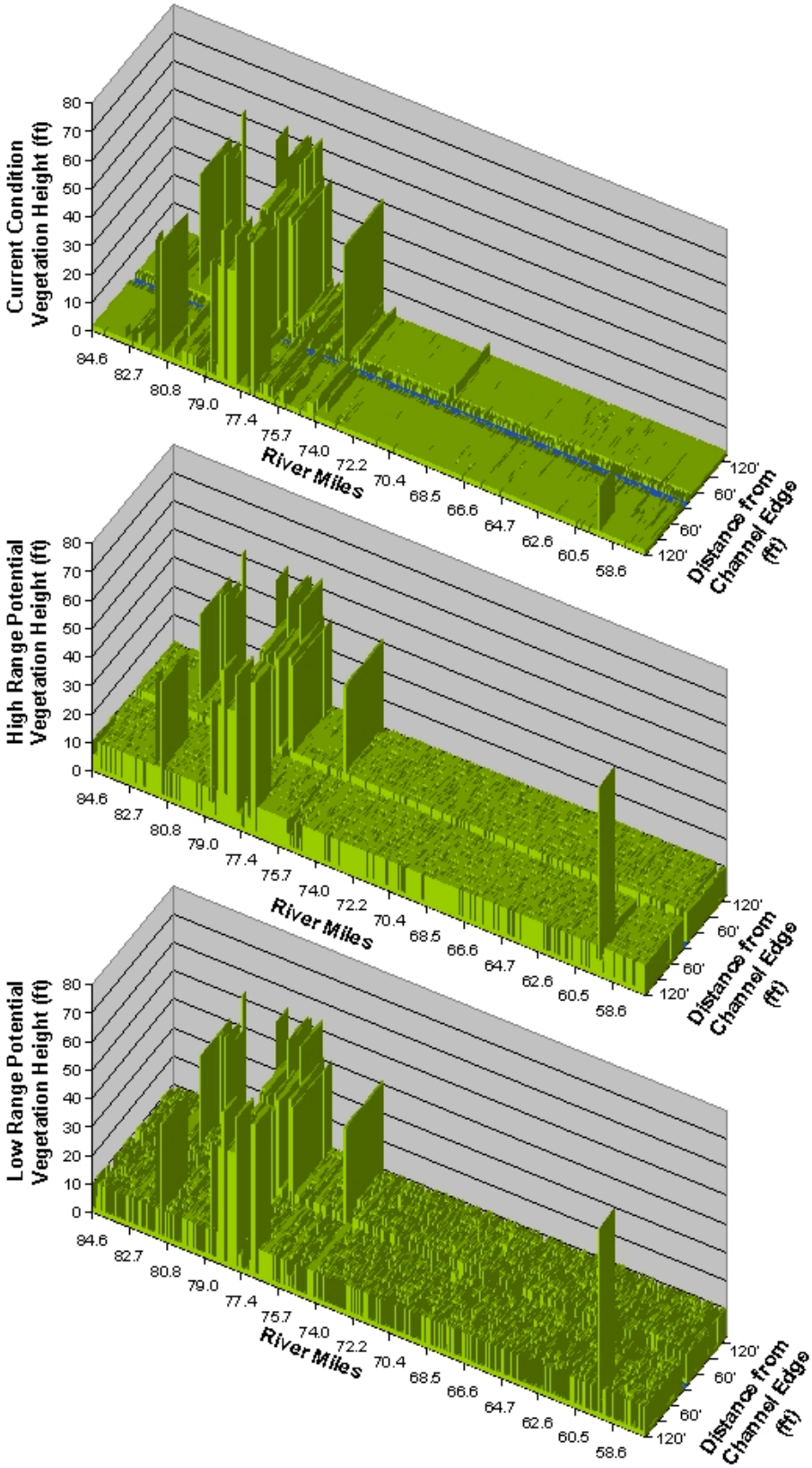


Figure 3-25. Sprague River Near Stream Land cover Height - River Miles 56.9 to 84.6

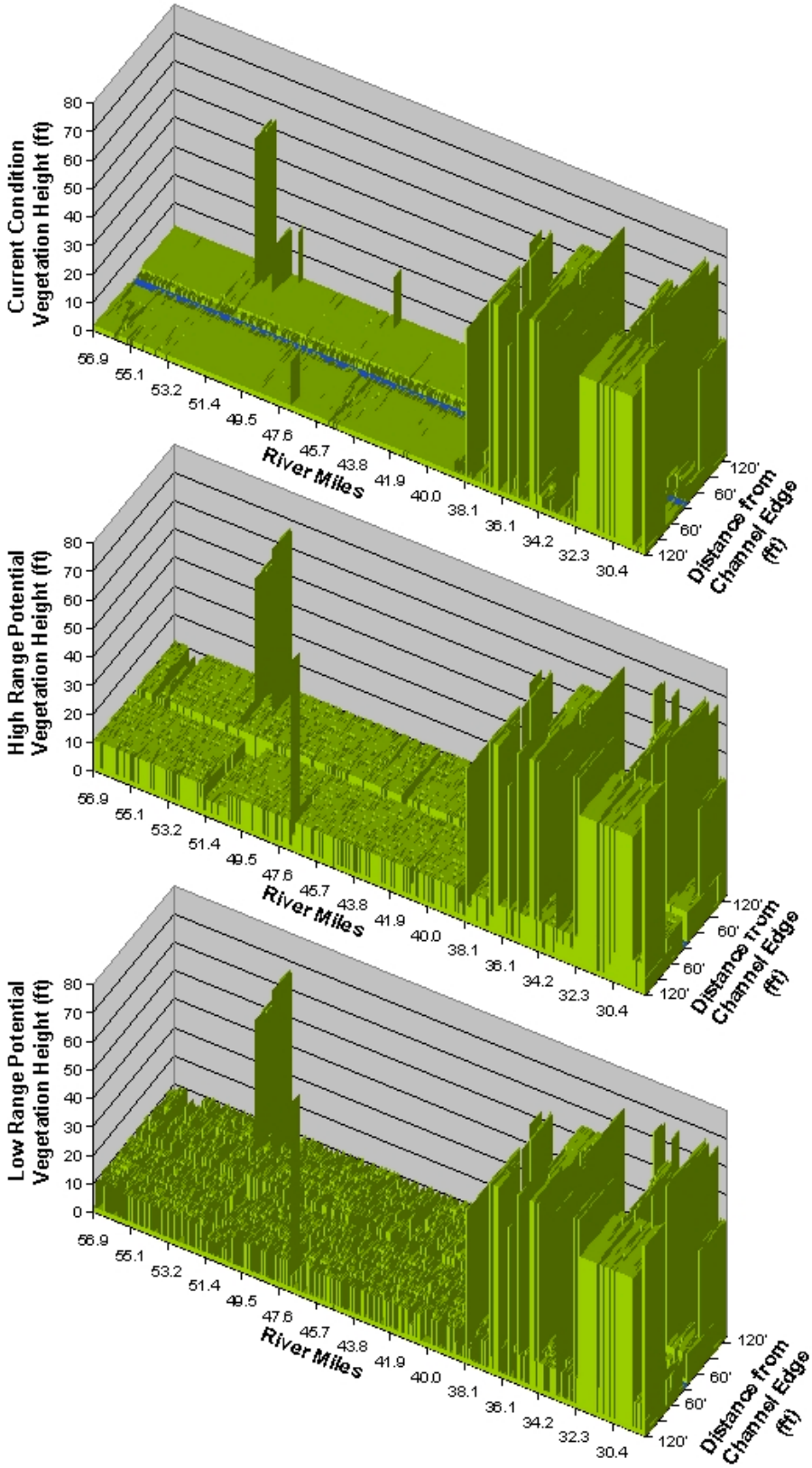


Figure 3-26. Sprague River Near Stream Land cover Height - River Miles 28.8 to 56.9

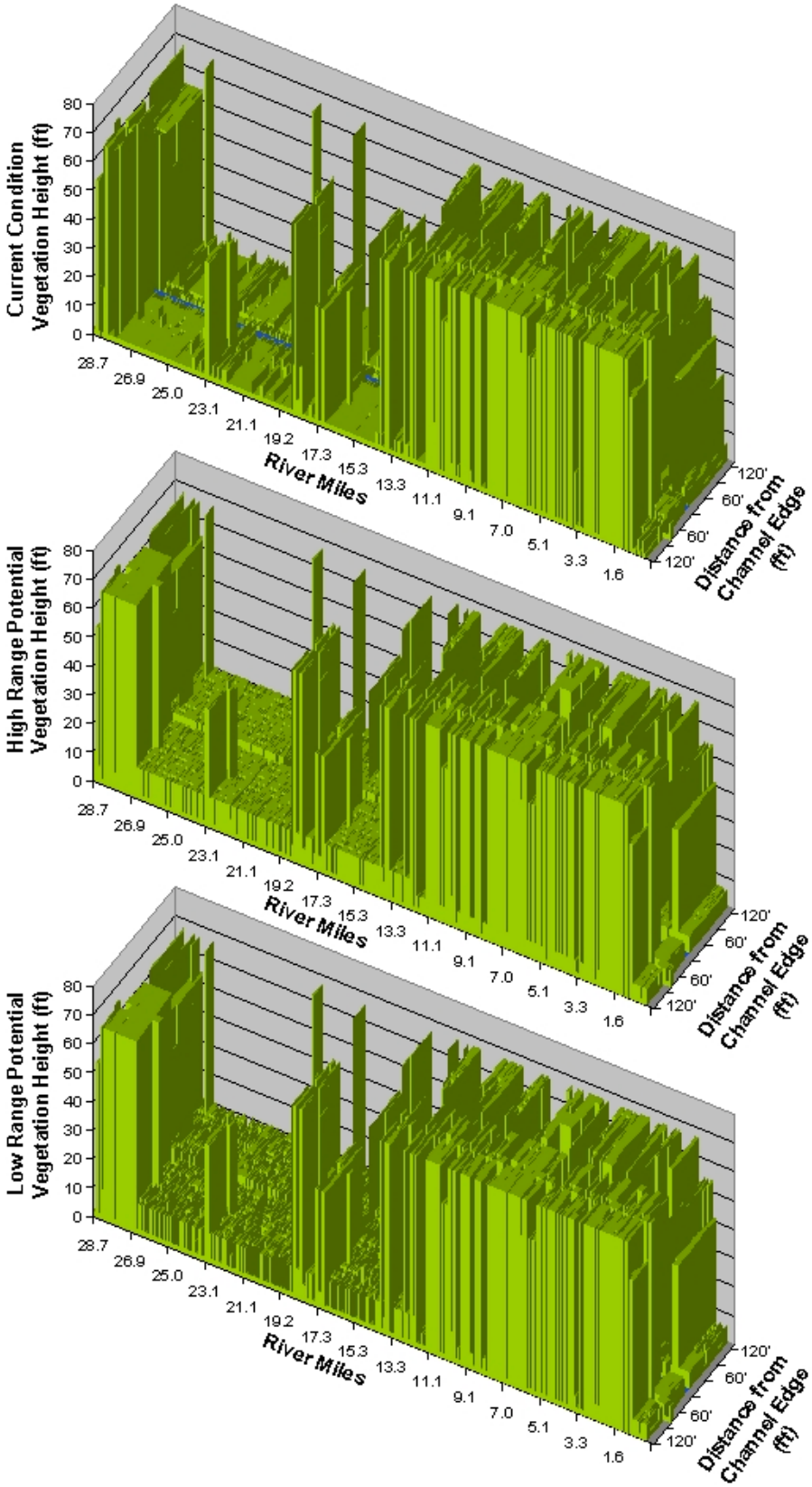


Figure 3-27. Sprague River Near Stream Land cover Height - River Miles 0.0 to 28.8

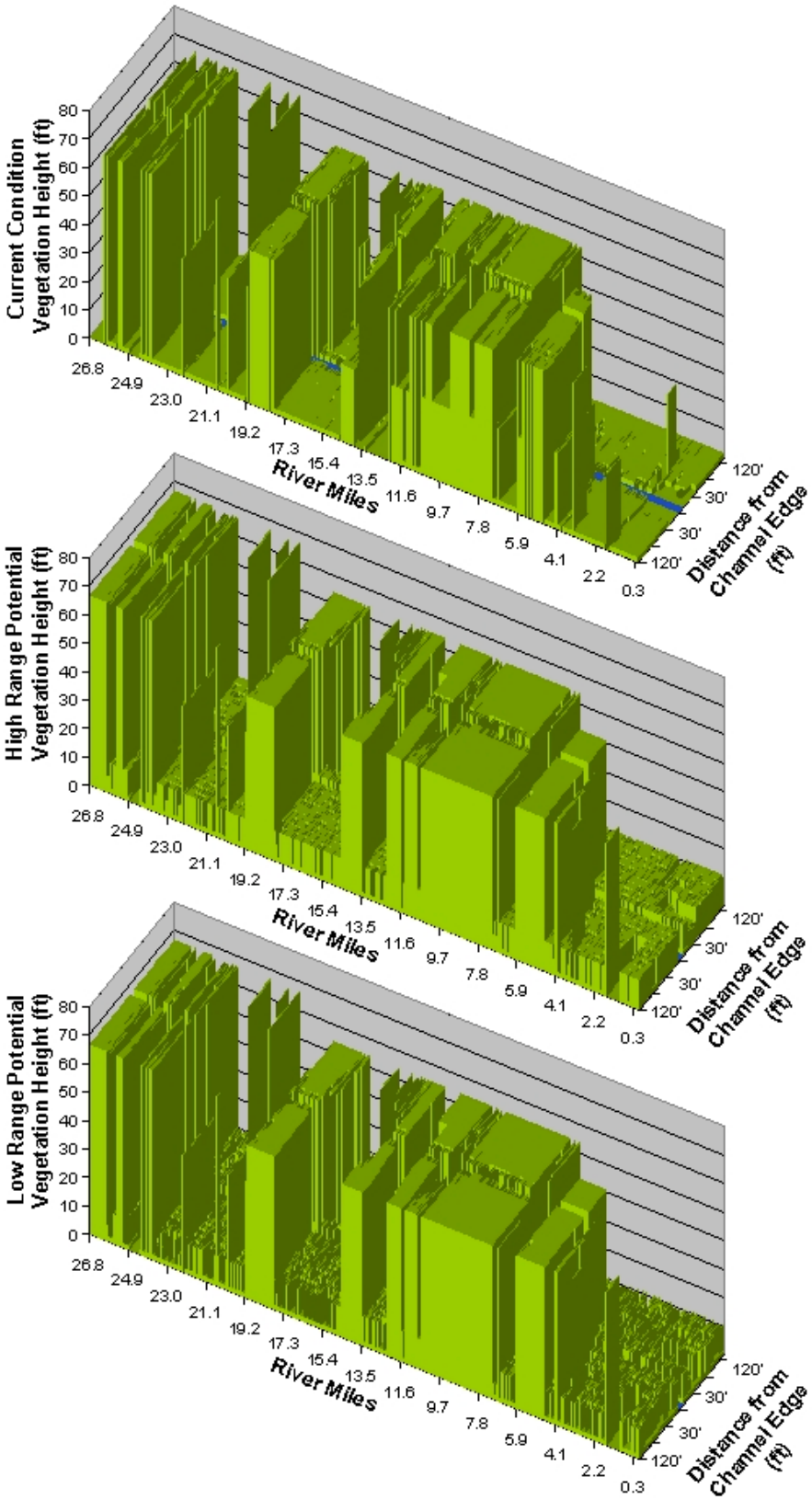


Figure 3-28. Fishhole Creek Near Stream Land cover Height - River Miles 0.0 to 28.0

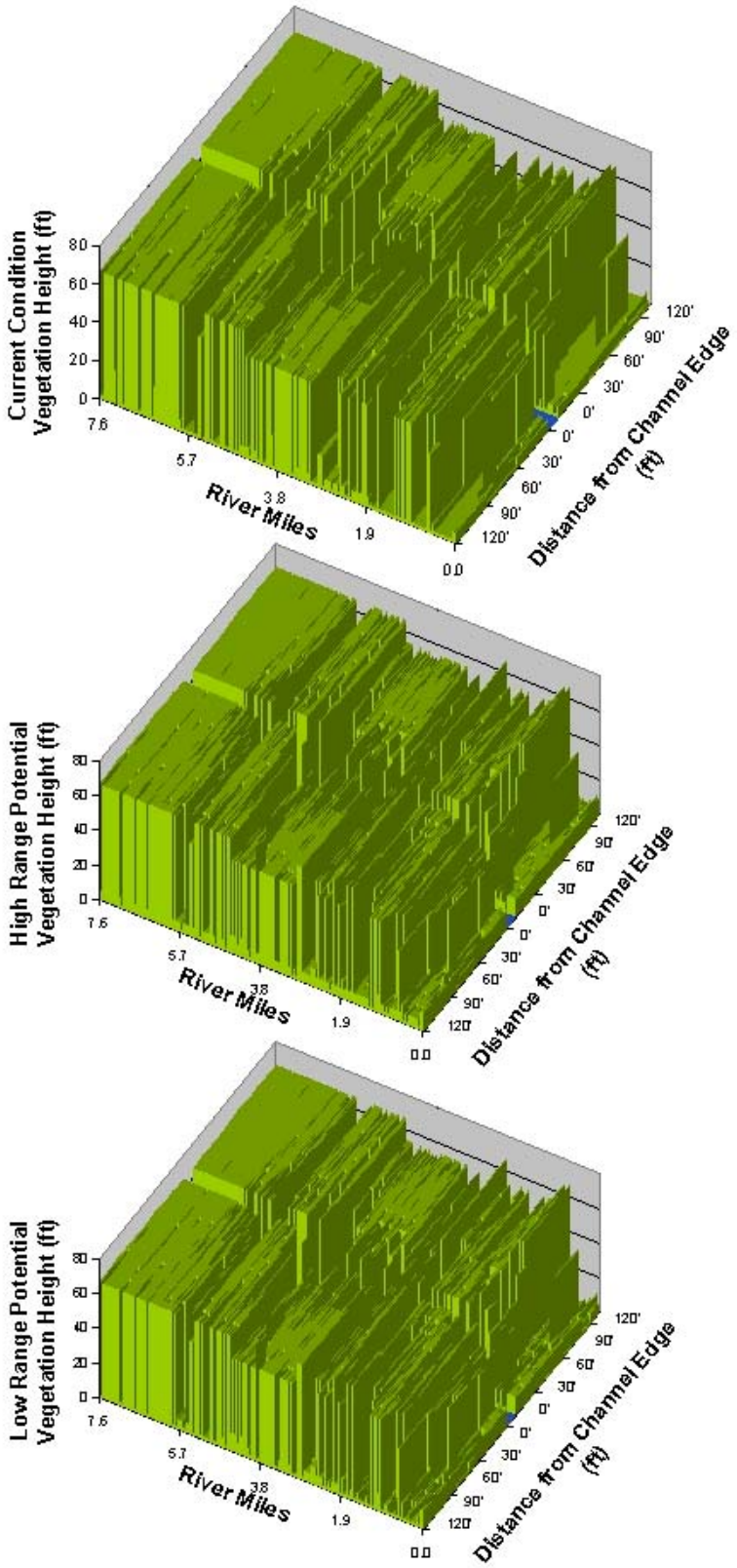


Figure 3-29. Trout Creek Near Stream Land cover Height - River Miles 0.0 to 8.0

3.6 Hydrology

3.6.1 Methodology Used for Mass Balance Development

FLIR sampled stream temperature data can be used to develop a mass balance for stream flow using minimal ground level data collection points. Simply identifying mass transfer areas is an important step in quantifying heat transfer within a stream network. For example, using FLIR temperature data, Oregon DEQ identified thirty-one mass transfer areas occurring in the North Fork Sprague River. Several of the subsurface mass transfer areas were unmapped and the relative thermal and hydrologic impact to the stream system was not previously quantified. Further, surface returns from agriculture irrigation were not quantified in terms of flow rates or temperatures.

N.F. Sprague River

10	tributary inflows
6	agriculture related return flows
9	subsurface inflows
+ 6	water withdrawals
31	Mass Transfer Processes

All stream temperature changes that result from mass transfer processes (i.e. tributary confluence, point source discharge, groundwater inflow, etc.) can be described mathematically using the following relationship:

$$T_{mix} = \frac{(Q_{up} \cdot T_{up}) + (Q_{in} \cdot T_{in})}{(Q_{mix})} = \frac{(Q_{up} \cdot T_{up}) + (Q_{in} \cdot T_{in})}{(Q_{up} + Q_{in})}$$

where,

Q_{up}: Stream flow rate upstream from mass transfer process
Q_{in}: Inflow volume or flow rate
Q_{mix}: Resulting volume or flow rate from mass transfer process ($Q_{up} + Q_{in}$)
T_{up}: Stream temperature directly upstream from mass transfer process
T_{in}: Temperature of inflow
T_{mix}: Resulting stream temperature from mass transfer process assuming complete mix

All water temperatures (i.e. T_{up}, T_{in} and T_{mix}) are apparent in the FLIR sampled stream temperature data. Provided that at least one instream flow rate is known the other flow rates can be calculated.

Water volume losses are often visible in FLIR imagery since diversions and water withdrawals usually contrast with the surrounding thermal signature of landscape features. Highly managed stream flow regimes can become complicated where multiple diversions and return flows mix or where flow diversions and returns are unmapped and undocumented. In such cases it becomes important to establish the direction of flow (i.e. influent or effluent). With the precision afforded by FLIR sampled stream temperatures, effluent flows can be determined when temperatures are the same. Temperature differences indicate that the flow is influent. This holds true even when observed temperature differences are very small. The rate of water loss from diversions or withdrawals cannot be easily calculated. Oregon DEQ estimates water withdrawal flow rates from the water right information maintained by Oregon Water Resources Department (OWRD).

In this fashion, a mass balance can be developed from relatively few instream measurements, FLIR stream temperature data and water rights data. **Potential flow rates** are easily calculated by removing all water withdrawals and agriculture return flows.

Discussion of Assumptions and Limitations for Mass Balance Methodology

1. **Small mass transfer processes are not accounted**. A limitation of the methodology is that only mass transfer processes with measured ground level flow rates or those that cause a quantifiable change in stream temperature with the receiving waters (i.e. identified by FLIR data) can be analyzed and included in the mass balance. For example, a tributary with an unknown flow rate that cause small temperature changes (i.e. less than $\pm 0.5^{o}F$) to the receiving stream cannot be accurately included. *This assumption can lead to an under estimate of influent mass transfer processes.*
2. **Limited ground level flow data limit the accuracy of derived mass balances**. Errors in the calculations of mass transfer can become cumulative and propagate in the methodology since validation can only be performed at sites with known flow rates. *These mass balance profiles should be considered estimates of a steady state flow condition*.
3. **Water withdrawals are not directly quantified**. Instead, water right data is obtained from the POD and WRIS OWRD databases. An assumption is made that these water rights are being used if water availability permits. *This assumption can lead to an over estimate of water withdrawals.*
4. **Water withdrawals are assumed to occur only at OWRD mapped points of diversion sites.** There may have been additional diversions occurring throughout the stream network. *This assumption can lead to an underestimate of water withdrawals and an under estimate of potential flow rates.*
5. **Return flows are oversimplified**. An assumption is made that all return flows are agriculture related and derive from water withdrawals and irrigation practices. While in many cases this may prove accurate, there are some areas where return flows occur at or near other natural mass transfer process (i.e. the confluence of a stream, subsurface inflows, etc.). Fishhole Creek serves as a good example for the failings of this assumption. The lower portion of Fishhole Creek is largely diverted and modified to serve as a collection point for irrigation water diverted from the South Fork Sprague River. It is impossible to distinguish Fishhole Creek potential flows, subsurface inflow rates and irrigation water withdrawn from the South Fork Sprague River. For simplicity, all of these flows are lumped as agriculture return flows. In the potential flow condition, all of these flows are removed from the South Fork Sprague River, and thus, Sprague River system. *This assumption can lead to an under estimate of potential flow rates.*
6. **It is not possible to determine the amount of return flows derived from ground water withdrawals relative to those derived from instream withdrawals.** Some of the irrigated water comes from ground water sources. Therefore, one should assume that portions of the return flows are derived from ground water sources. Return flows can occur over long distances from irrigation application and generally occur at focal points down gradient from multiple irrigation applications. It is not possible to estimate the portion of irrigation return flow that was pumped from ground water rights. In the potential flow condition all return flows are removed from the mass balances. *This assumption can lead to an under estimate of potential flow rates.*
7. **Return flows may deliver water that is diverted from another watershed.** In some cases, irrigation canals transport diverted water to application areas in another drainage. This is especially common in low gradient meadows, cultivated fields and drained wetlands used for agriculture production. An example is Five Mile Creek, a tributary to the North Fork Sprague River. Water withdrawn from Five Mile Creek is applied in lateral areas. Return flows derived from these withdrawals occur directly to the North Fork Sprague River, instead of returning to Five Mile Creek. Fishhole Creek also experiences a similar change in instream flows. The result is that accounting for a tributary flow in the potential flow condition is extremely difficult. ODEQ is unable to track return flows to withdrawal origins between drainage areas. *When return flows are removed in the potential flow condition this assumption can lead to an under estimate of potential tributary flow rates.*

Table 3-6. Mass transfer processes and cumulative flow rates by drainage area.

	Number of Mass Transfer Processes					Mass Transfer Process Flow Rates (cfs)					
	Tributary Inflows	Agriculture Return Flows	Subsurface Inflows	Water Withdrawals	Total	Upstream Boundary Condition[13]	Tributary Inflows[14]	Agriculture Return Flows[15]	Subsurface Inflows[16]	Water Withdrawals[17]	Total Flow per Drainage[18]
N.F. Sprague R.	10	6	9	6	31	15	29	9	11	-28	35
S.F. Sprague R.	6	7	4	5	22	4	24	12	7	-15	31
Sycan R.	1	2	11	11	25	5	4	13	41	-33	29
Sprague R.	6	11	23	47	87	0[19]	116	101	358	-226	349
Williamson R.	9	12	14	47	82	16[20] 23[21]	394	55	274	-572	181
Totals	32	38	61	116	247	40	567	190	690	-874	

[13] The upstream boundary condition is the upper most extent for which the mass balance was completed (North Fork Sprague River - RM 32.4, South Fork Sprague River - RM 30.0, Sycan River - RM 36.0, Sprague River - RM 84.6 and Williamson River - RM 82.5).

[14] Tributary flows are identified and quantified using FLIR data and derived mass balance flows.

[15] Agriculture return flows are identified and quantified using FLIR data and derived mass balance flows.

[16] Subsurface flows are identified and quantified using FLIR data and derived mass balance flows.

[17] Water withdrawals are calculated from OWRD databases for points of diversion and the water rights information system. Data base queries and linking are performed by ODEQ staff.

[18] The total flow per drainage represents the flow at the mouth of each stream system.

[19] The Sprague River upstream boundary condition is the confluence of the South and North Fork Sprague Rivers. The addition of these two flows as tributaries is 66.2 (South Fork Sprague River - 30.8 cfs and North Fork Sprague River - 35.3 cfs).

[20] Upper Williamson boundary condition downstream Williamson Spring (RM 82.5)

[21] Lower Williamson boundary condition downstream Upper Klamath Marsh (RM 41.6)

3.6.2 Results - Mass Balances

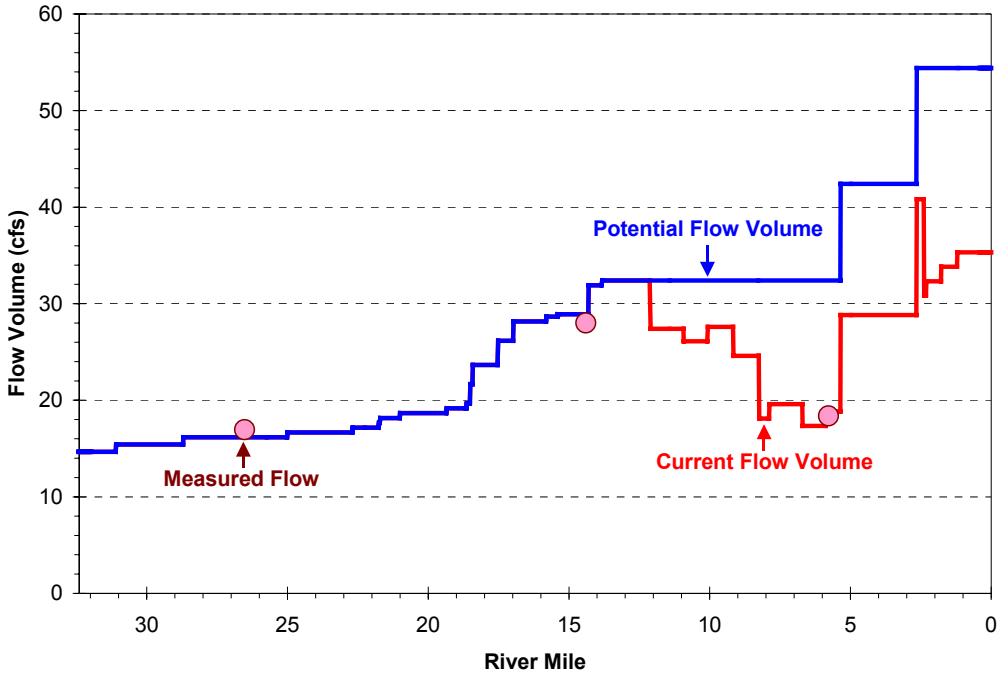


Figure 3.30. *Mass balance developed for the North Fork Sprague River using instream gage data, FLIR temperature data and water rights data.*

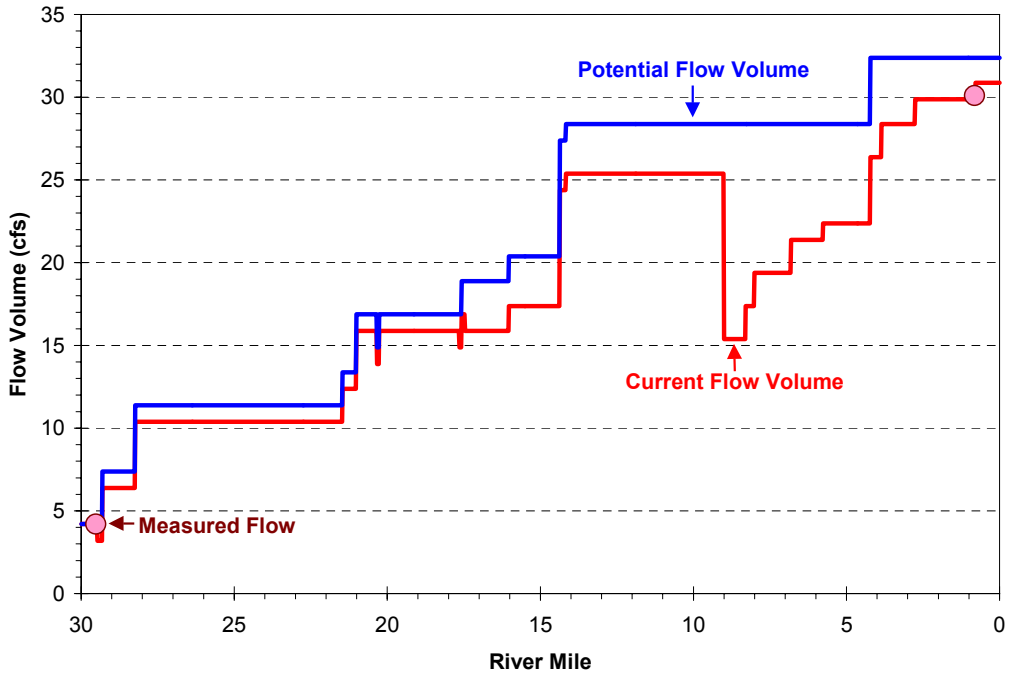


Figure 3.31. *Mass balance developed for the South Fork Sprague River using instream gage data, FLIR temperature data and water rights data.*

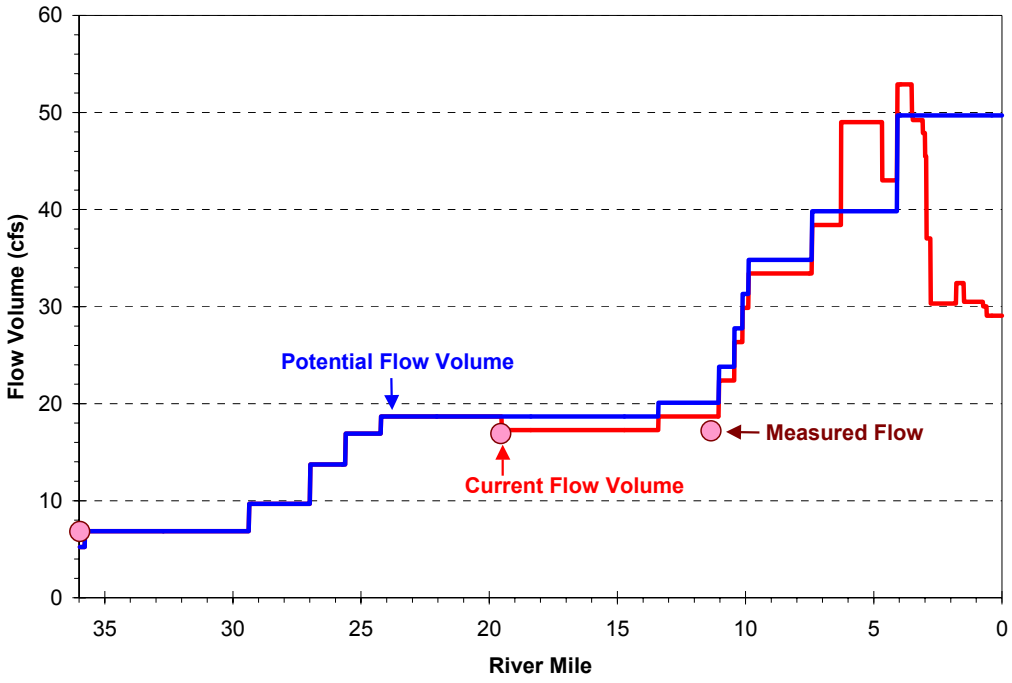


***Figure 3.32**. Mass balance developed for the Sycan River using instream gage data, FLIR temperature data and water rights data.*

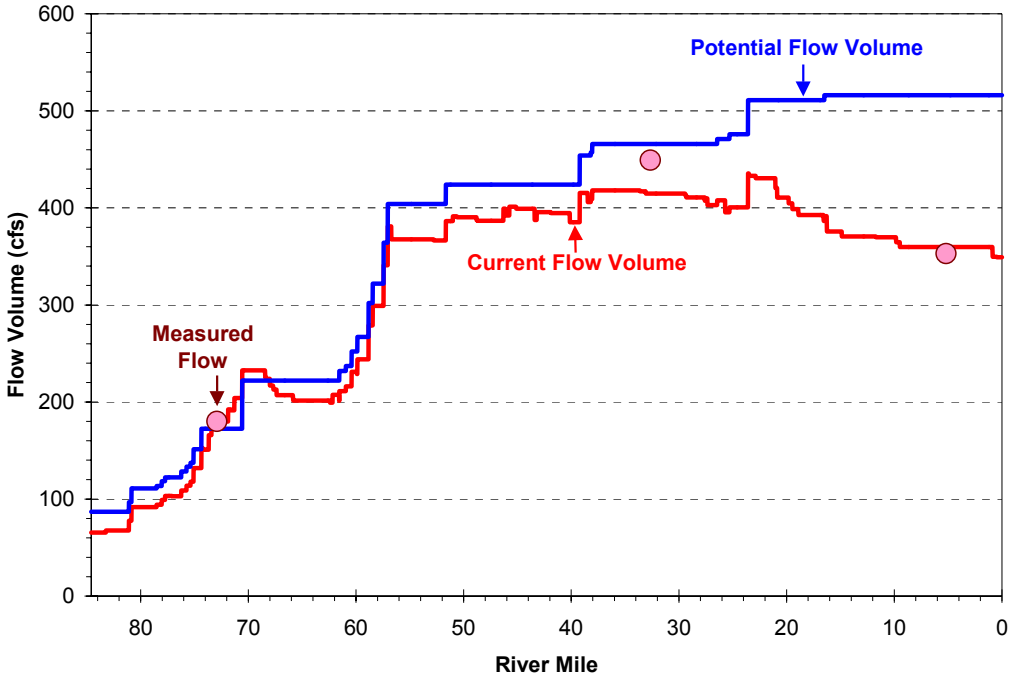


***Figure 3.33**. Mass balance developed for the Sprague River using instream gage data, FLIR temperature data and water rights data.*

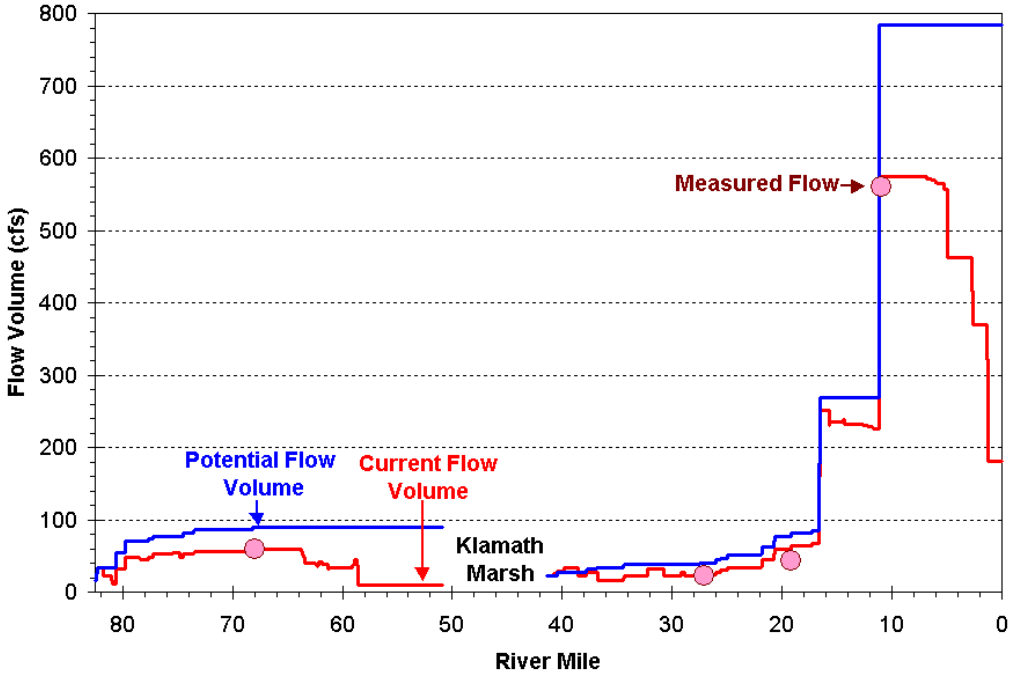


***Figure 3.34**. Mass balance developed for the Williamson River using instream gage data, FLIR temperature data and water rights data. Downstream of Klamath Marsh the mass balance is reset to current condition flows (RM 41.6) due to geologic constraints cause by the a basalt sill. Analysis demonstrates that downstream flows become independent of flows above Klamath Marsh when marsh water table elevations drop to levels of 0.3' or less of the basalt sill (La Marche. 1999).*

3.7 Topographic Shade Angle

The maximum **topographic shade angle** is calculated to the east, south and west, relative to the stream segment node. In each direction (east, south and west) Ttools steps away from the stream sampling every other pixel for elevation and calculating topographic shade angle. Ttools records the value (in degrees) and the X and Y coordinates of the point that represents maximum topographic shade angle.

$$\text{Topographic Angle} = \tan^{-1}\left(\frac{\text{Elevation Above Stream}}{\text{Distance from Stream}}\right)$$

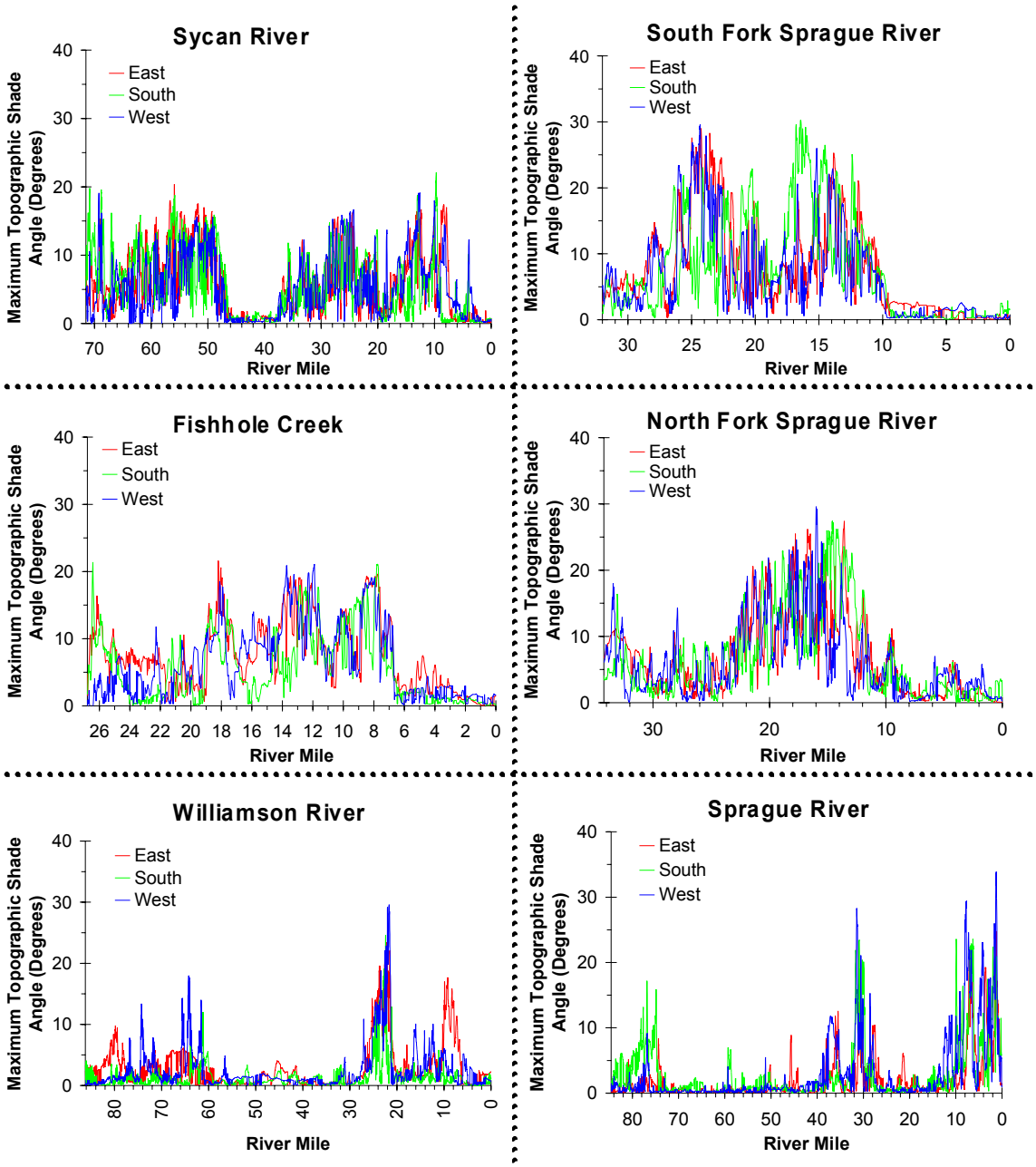


Figure 3.35. *Maximum topographic shade angles sampled from digital elevation models.*

CHAPTER 4. SIMULATIONS

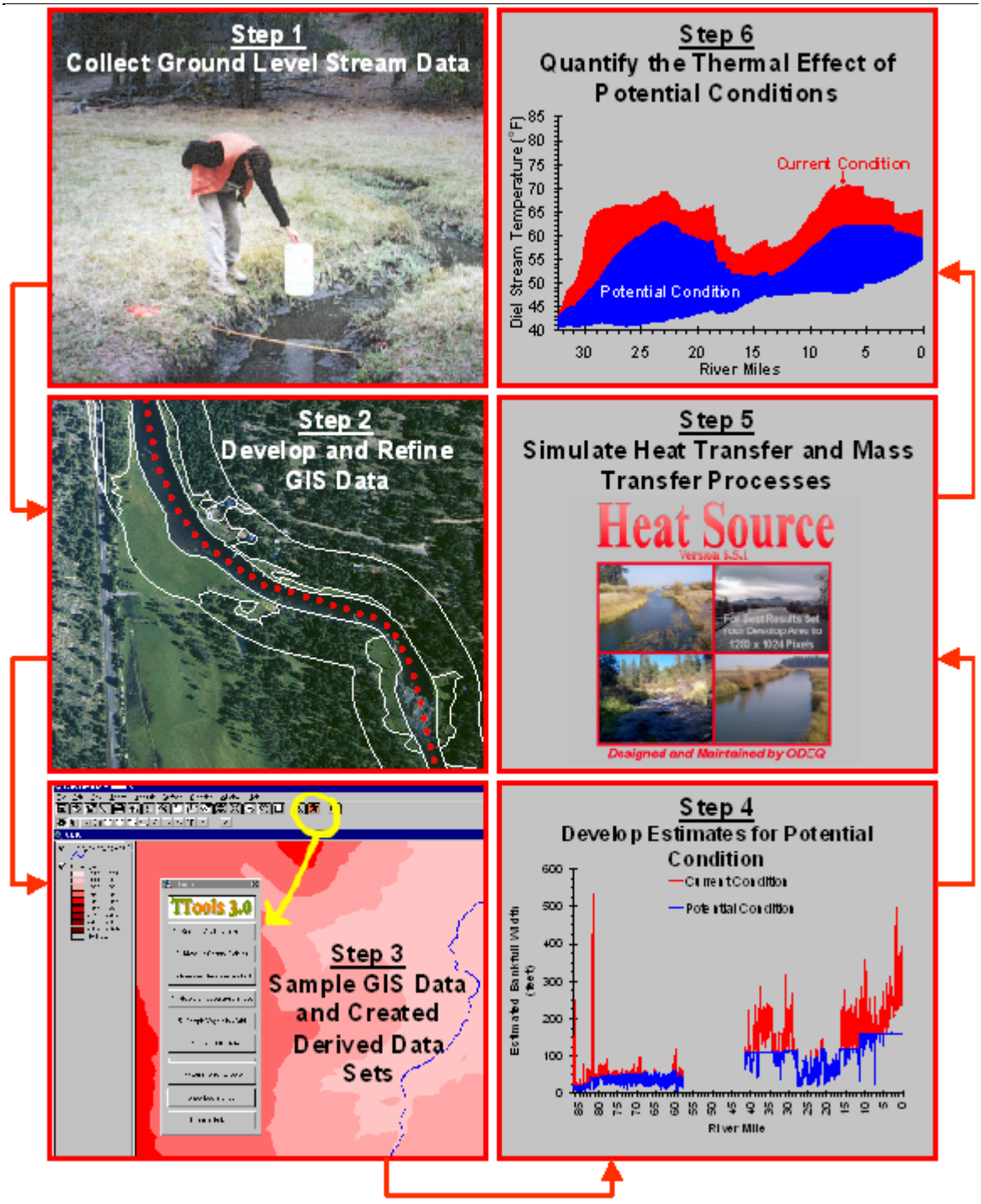


Figure 4-1. *Steps used in the stream temperature simulation methodology.*

Terms Used in this Chapter

Average Deviation – The absolute average between deviations of known x's and known y's.

Calibration – Simulation models are often refined by adjusting parameters and input data to increase model performance.

Correlation Coefficient – R-Squared Value - The Pearson product moment calculated for two data sets. The r-squared value can be interpreted as the proportion of the variance in y attributable to the variance in x.

Heat Source – A stream temperature computer model that is maintained by ODEQ.

Potential Daily Solar Load – The solar heat load that would be received without attenuation or scattering from land cover (i.e. in the absence of stream surface shade)

Sample Size (n) – The number of discrete measurements or simulated values

Shade Curve – Effective shade for a particular land cover type, latitude and time period for varying channel width values.

Solar Altitude – The vertical angle of the sun during daytime

Solar Azimuth – The horizontal angle of the sun during daytime

Solar Heat Flux – Rate of heating per unit area from solar radiation. For the purposes of this analysis, the solar heat flux is the rate of heat delivery to the stream water column accounting for topographic shading, atmospheric and land cover attenuation and scattering, surface reflection, and stream transmissivity.

Solar Heat Load – Heat derived from solar radiation per day in a given stream segment. For the purposes of this analysis, the solar heat load is the heat delivered to the stream water column.

Total Solar Heat Load – Total daily heat delivery to the stream in the current condition.

Background Solar Heat Load – An estimate of the solar heat load under potential land cover and channel morphology conditions. This condition implies no anthropogenic warming from nonpoint sources.

Nonpoint Source Solar Heat Load – Derived by subtracting the nonpoint source solar heat load from the total solar heat load.

Simulation Scenario – Running a simulation while changing the values of one or more of the input parameters, such as land cover or channel width.

Solar Radiation – Radiant heat derived from the sun.

Solar Zenith – The mid-day angle at which the sun is highest in the sky.

Standard Error – A measure of the amount of error in the prediction of a value for an individual known value

System Potential – For the purposes of this analysis, potential conditions are defined for both land cover and channel width. System potential condition occurs when both land cover and channel width are at potential. This condition implies that a condition of no anthropogenic disturbance.

Transmissivity – A dimensionless value measured as the fraction of incident radiation that is transmitted through the body

Ttools – A GIS sampling tool developed and maintained by ODEQ used to build input data sets for channel morphology, land cover and FLIR.

Validation – Statistical quantification of simulation model performance.

4.1 Overview of Modeling Purpose, Valid Applications & Limitations

4.1.1 Channel Morphology Analysis

Modeling Purpose

- Quantify existing Rosgen stream types and morphologic parameters.
- Develop a methodology to estimate a potential equilibrium condition for channel morphology.
- Establish threshold bankfull channel width conditions for the stream network, above which channel conditions are considered to deviate from a potential equilibrium condition.

Valid Applications

- Estimate bankfull channel cross-sectional area as a function of drainage area.
- Estimate bankfull channel width as a function of drainage area and Rosgen stream type.
- Identify site-specific deviations of current condition bankfull channel width from threshold potential conditions.

Limitations

- Methodology is based on hydrologic data such as, local gage data, GIS data and average width to depth ratios by Rosgen stream type. Each data source has accuracy considerations.
- Methodology is based on hydrologic relationships such as, rating curves for multiple channel parameters. Each rating curve developed in this document has validation statistics provided in **Section 3.4 Channel Morphology**.
- Limited gage data within the Upper Klamath Lake Drainage does not allow regional curve validation for drainage areas greater than 100 mi^2 (260 km^2).
- Many areas within the Upper Klamath Lake Drainage are not analyzed. This analytical effort provides site specific bankfull channel width targets for 321.8 river miles of the 3008.3 river miles of the mapped stream network. Therefore, 10.7% of the stream network has developed site specific bankfull channel width targets.
- All applications of the channel morphology analytical methods should consider validation statistics presented in **Section 3.4 Channel Morphology**.

4.1.2 Near Stream Land Cover Analysis

Modeling Purpose

- Quantify existing near stream land cover types and physical attributes.
- Develop a methodology to estimate potential conditions for near stream land cover.
- Establish threshold near stream land cover type and physical attributes for the stream network, below which land cover conditions are considered to deviate from a potential condition.

Valid Applications

- Estimate current condition near stream land cover type and physical attributes.
- Estimate potential condition near stream land cover type and physical attributes.
- Identify site-specific deviations of current near stream land cover conditions from threshold potential conditions.

Limitations

- Methodology is based on ground level and GIS data such as, vegetation surveys, and digitized polygons from air photos. Each data source has accuracy considerations.
- Associations used for land cover classification are assigned median values to describe physical attributes, and in some cases, this methodology significantly underestimates landscape variability.
- Uncertainty regarding shrub and graminoid/forb potential distributions exists to a high degree. Large ranges of near stream land cover type distributions are used to assess multiple potential conditions.
- Many areas within the Upper Klamath Lake Drainage are not analyzed. This analytical effort provides site specific near stream land cover targets for 321.8 river miles of the 3008.3 river miles of the mapped stream network. Therefore, 10.7% of the stream network has developed site specific near stream land cover targets.

4.1.3 Hydrology Analysis

Modeling Purpose

- Map and quantify surface and subsurface flow inputs and withdrawal outputs.
- Develop a mass balance for the stream network by quantify existing instream flow volume
- Quantify average velocity and average stream depth as a function of flow volume, stream gradient, average channel width and channel roughness.
- Develop a potential mass balance that estimates flow volumes when withdrawals and artificial surface returns are removed.

Valid Applications

- Estimate current condition flow volume, velocity and stream depth.
- Estimate potential condition flow volume, velocity and stream depth.
- Identify site specific deviations of current mass balance from the threshold potential mass balance.

Limitations

- Small mass transfer processes are not accounted.
- Limited ground level flow data limit the accuracy of derived mass balances.
- Water withdrawals are not directly quantified
- Water withdrawals are assumed to occur only at OWRD mapped points of diversion.
- Return flows are oversimplified.
- It is not possible to determine the amount of return flows derived from ground water withdrawals relative to those derived from instream withdrawals.
- Return flows may deliver water that is diverted from another watershed.
- Many areas within the Upper Klamath Lake Drainage are not analyzed. This analytical effort provides site-specific mass balance values for 321.8 river miles of the 3008.3 river miles of the mapped stream network. Therefore, 10.7% of the stream network has developed site-specific mass balance values.
- Inter-annual variations are not simulated.
- Intra-annual variations are not simulated.

4.1.4 Effective Shade Analysis

Modeling Purpose

- Simulate current condition effective shade levels over stream network.
- Simulate potential condition effective shade levels based on channel width and land cover types and physical attributes over stream network.
- Establish threshold effective shade values for the stream network, below which current conditions are considered to deviate from a potential condition.
- Provide land cover type specific shade curves that allows target development where site-specific targets are not completed.

Valid Applications

- Estimate current condition effective shade over the stream network.
- Estimate potential condition effective shade over the stream network.
- Identify site-specific deviations of current effective shade conditions from threshold potential conditions.

Limitations

- Limitations for input parameters apply (i.e. channel morphology and near stream land cover type and physical attributes).
- A range of effective shade outputs is simulated due to the high degree of uncertainty regarding shrub and graminoid/forb potential distributions. This range of effective shade outputs can be large.
- Accuracy of the methodology is limited to roughly $\pm$ 8% effective shade.
- The period of simulation is valid for effective shade values that occur in late July and early August.
- Many areas within the Upper Klamath Lake Drainage are not analyzed. This analytical effort provides site-specific effective shade targets for 321.8 river miles of the 3008.3 river miles of the mapped stream network. Therefore, 10.7% of the stream network has developed site-specific effective shade targets.

4.1.5 Stream Temperature Analysis

Modeling Purpose

- Analyze critical condition stream temperature over stream network.
- Analyze potential condition stream temperature based on channel width, land cover types and physical attributes and flow volume over stream network.
- Establish threshold stream temperature values for the stream network, above which current conditions are considered to deviate from a potential condition.
- Demonstrate that stream temperature regimes are significantly different in a condition that minimizes anthropogenic warming.
- Provide a reasonable assurance that beneficial uses are protected in the potential condition to the extent possible given the natural constraints for channel morphology and land cover type and physical attributes.
- Provide a robust methodology for stream temperature analysis, provided data and analytical constraints.

Valid Applications

- Estimate critical condition stream temperatures over the stream network.
- Estimate potential critical condition stream temperatures over the stream network.
- Identify site-specific deviations of current stream temperatures from potential conditions.
- Analyze the sensitivity of single or multiple parameters on stream temperature regimes.
- Identify stream temperature distributions during critical conditions.

Limitations

- Limitations for input parameters apply (i.e. channel morphology, near stream land cover type and physical attributes and hydrology).
- A range of stream temperature outputs is simulated due to the high degree of uncertainty regarding shrub and graminoid/forb potential distributions. This range of stream temperature outputs can be large.
- Accuracy of the methodology is limited to roughly $\pm$ 1.2^{o}F ($\pm$ 0.7^{o}F).
- Marshes are not analyzed. Upper Klamath Lake is not analyzed.
- Stream temperature results are limited to the streams for which the analysis is completed (i.e. Williamson River, Sprague River, Sycan River, N.F. Sprague River and S.F. Sprague River). Application of the stream temperature output to other streams within or outside of the Upper Klamath Lake Drainage is not valid.
- The period of simulation is valid for stream temperature values that occur in late July and early August.
- Inter-annual variations are not simulated.
- Intra-annual variations are not simulated.
- Many areas within the Upper Klamath Lake Drainage are not analyzed. This analytical effort provides site specific critical condition stream temperature values for 266.0 river miles of the 3008.3 river miles of the mapped stream network. Therefore, 8.8% of the stream network has simulated site specific critical condition stream temperature values.

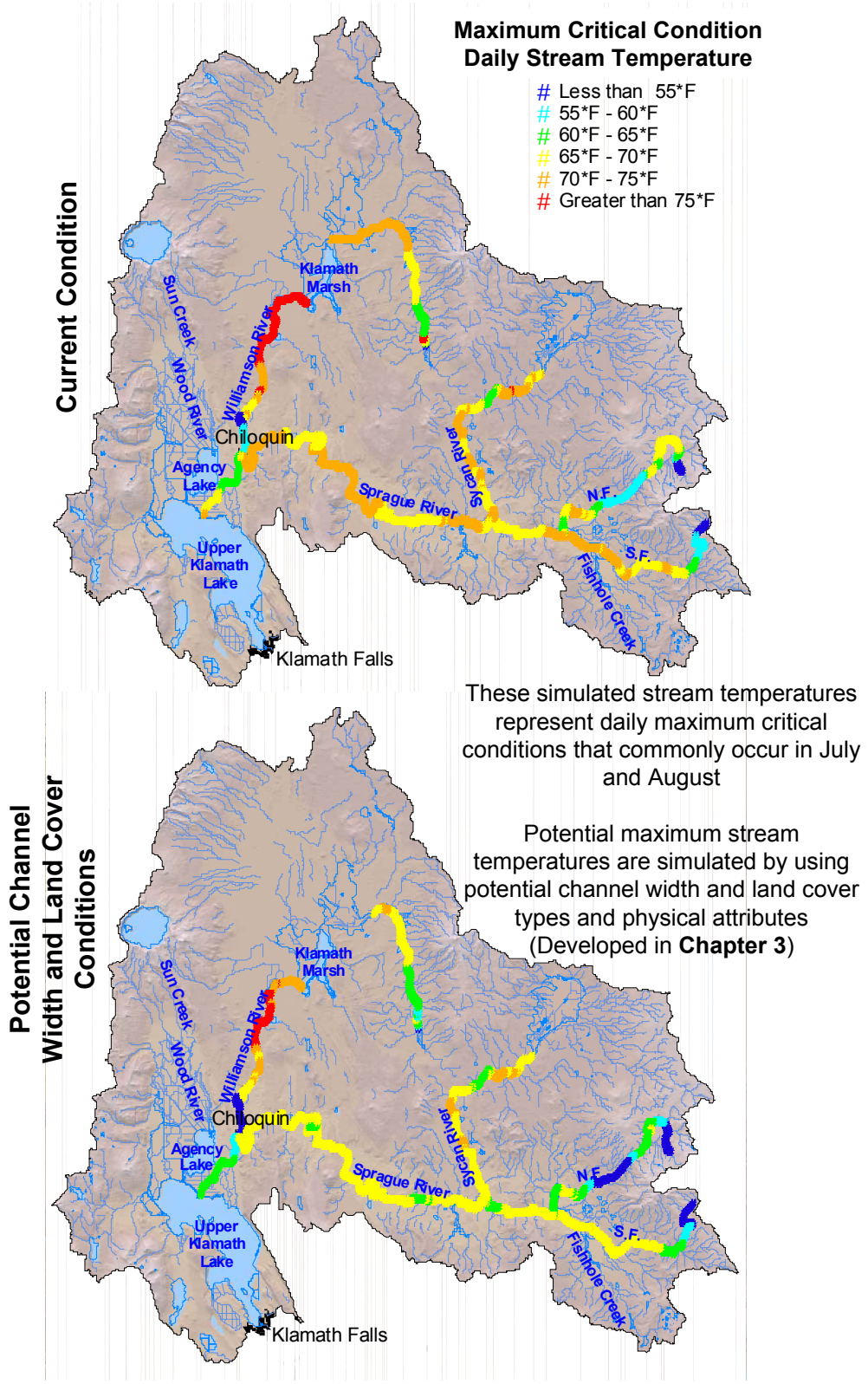


***Figure 4-2**. Simulated maximum daily stream temperatures for current conditions and potential channel width, land cover conditions (late July to mid-August period).*

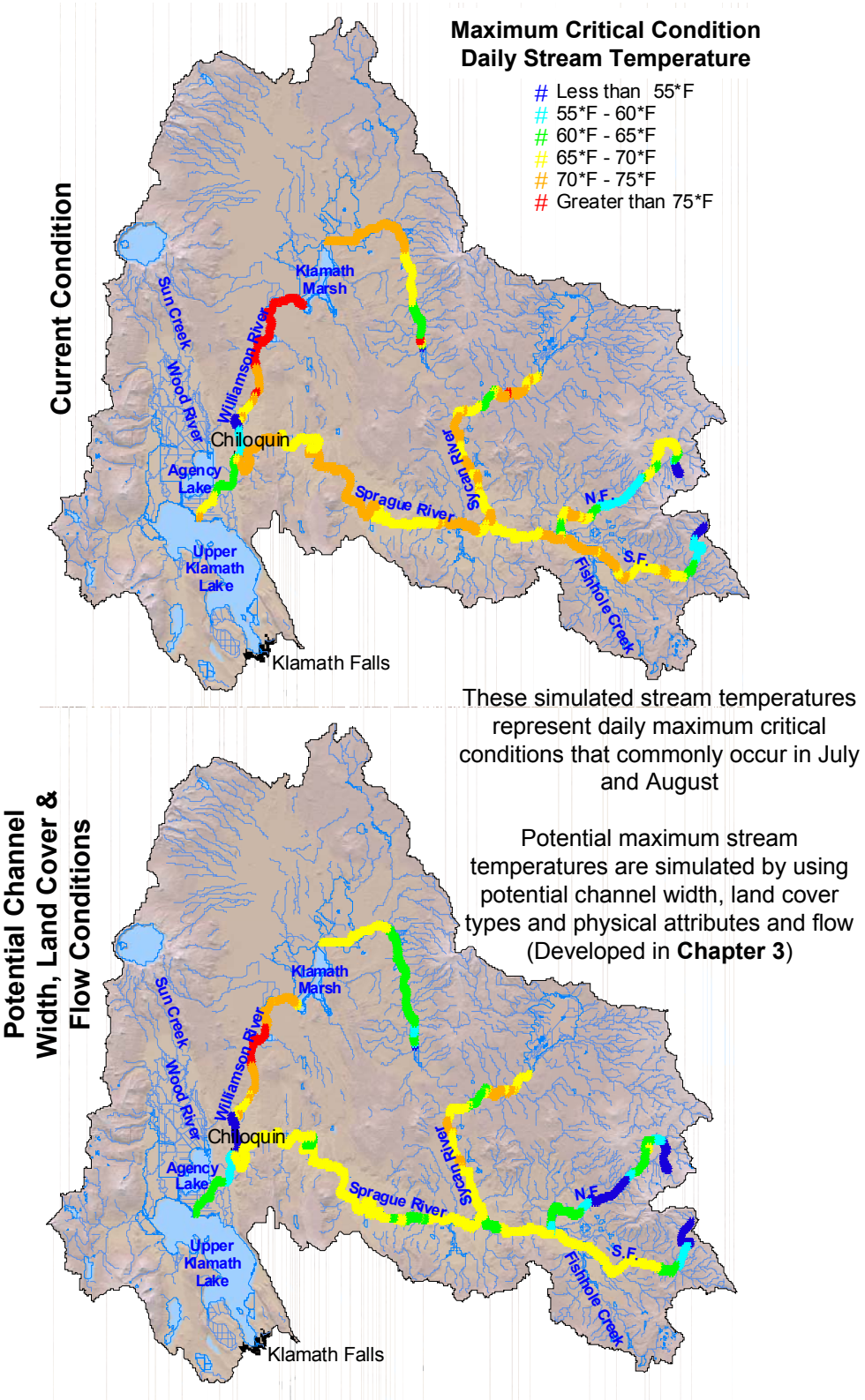


***Figure 4-3**. Simulated maximum daily stream temperatures for current conditions and potential channel width, land cover and flow conditions (late July to mid-August period).*

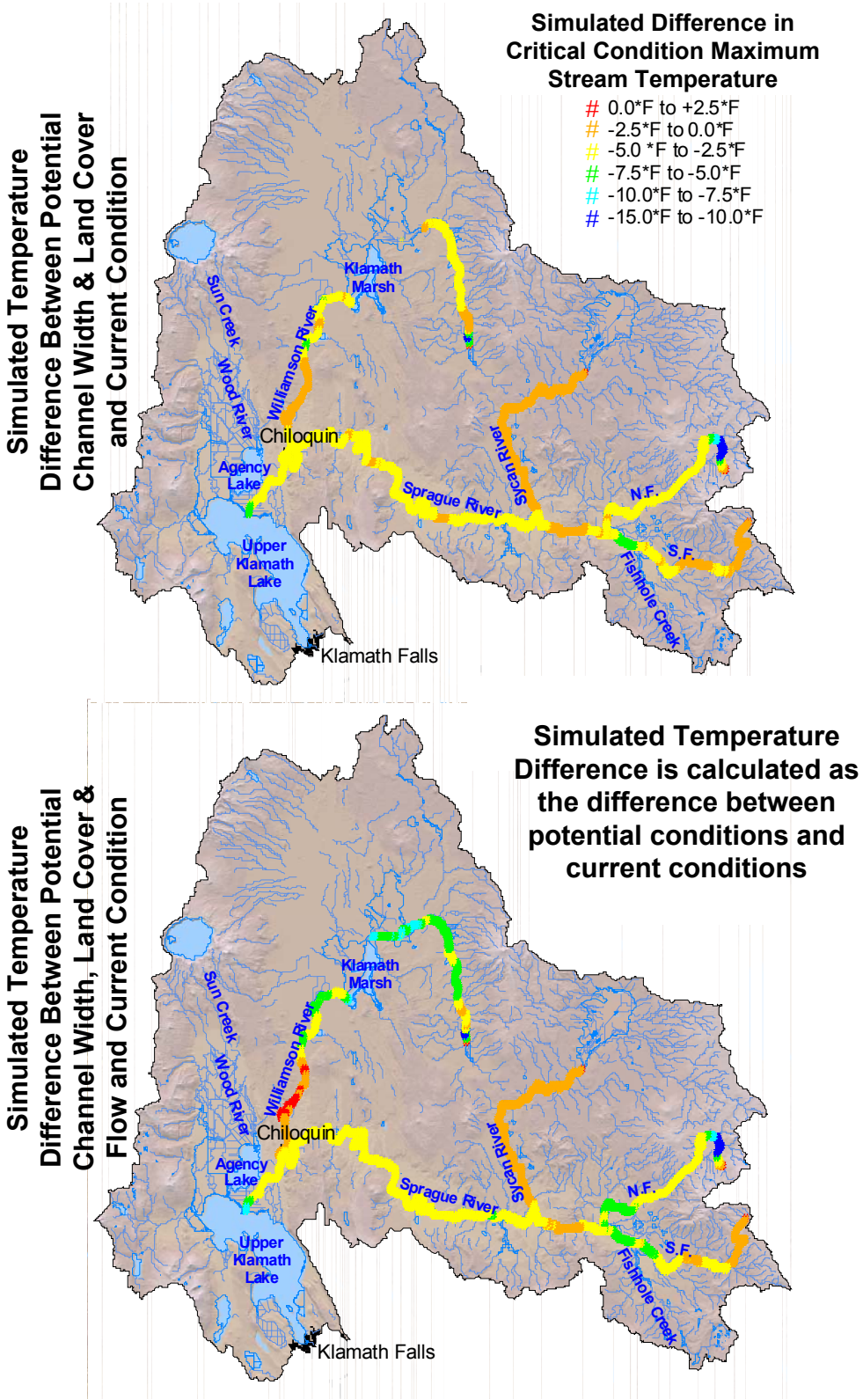


Figure 4-4. *Simulated difference between maximum daily stream temperatures for current conditions and potential conditions (late July to mid-August period).*

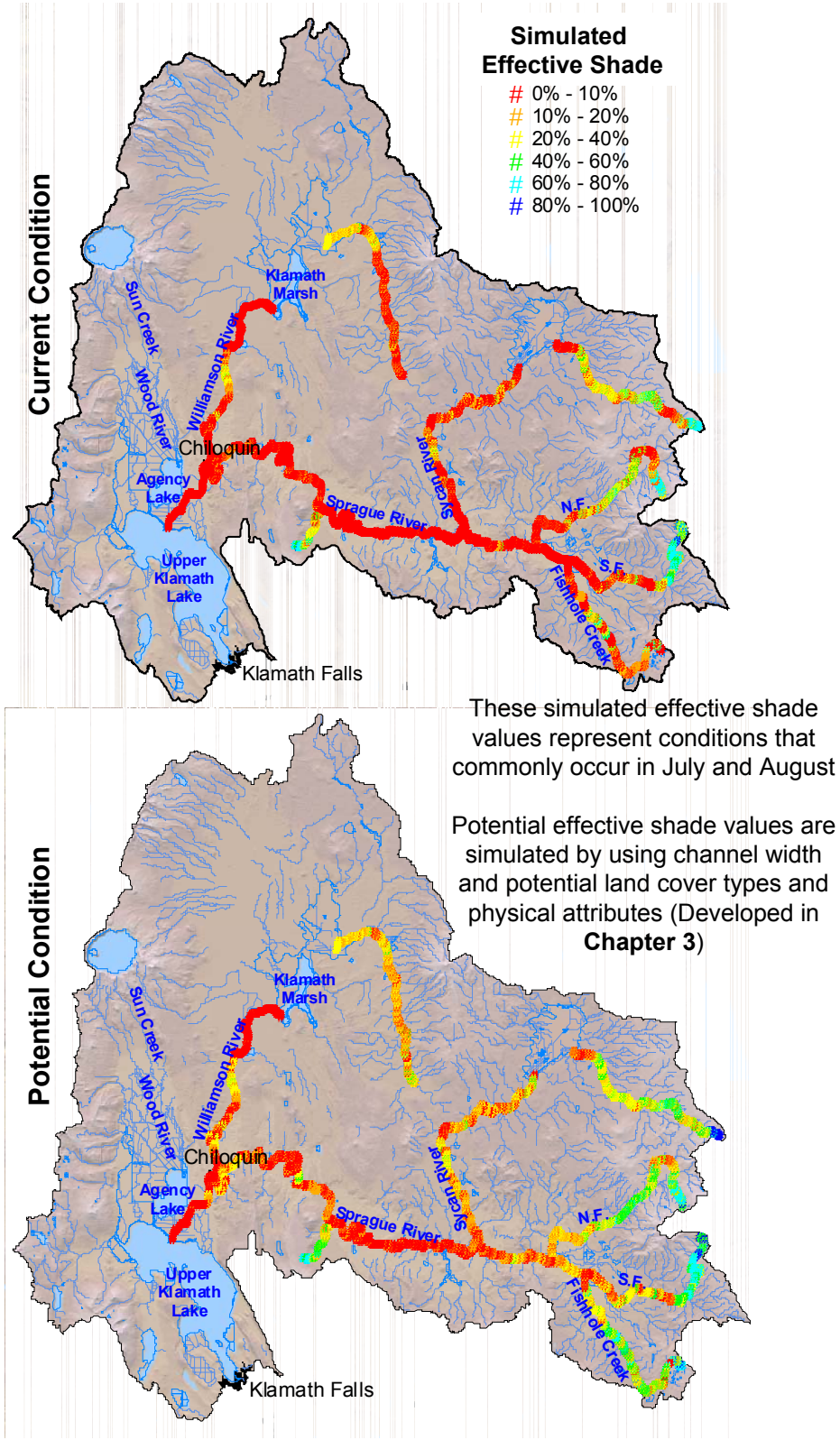


***Figure 4-5**. Simulated effective shade – current conditions and potential channel width and land cover conditions (July to August period).*

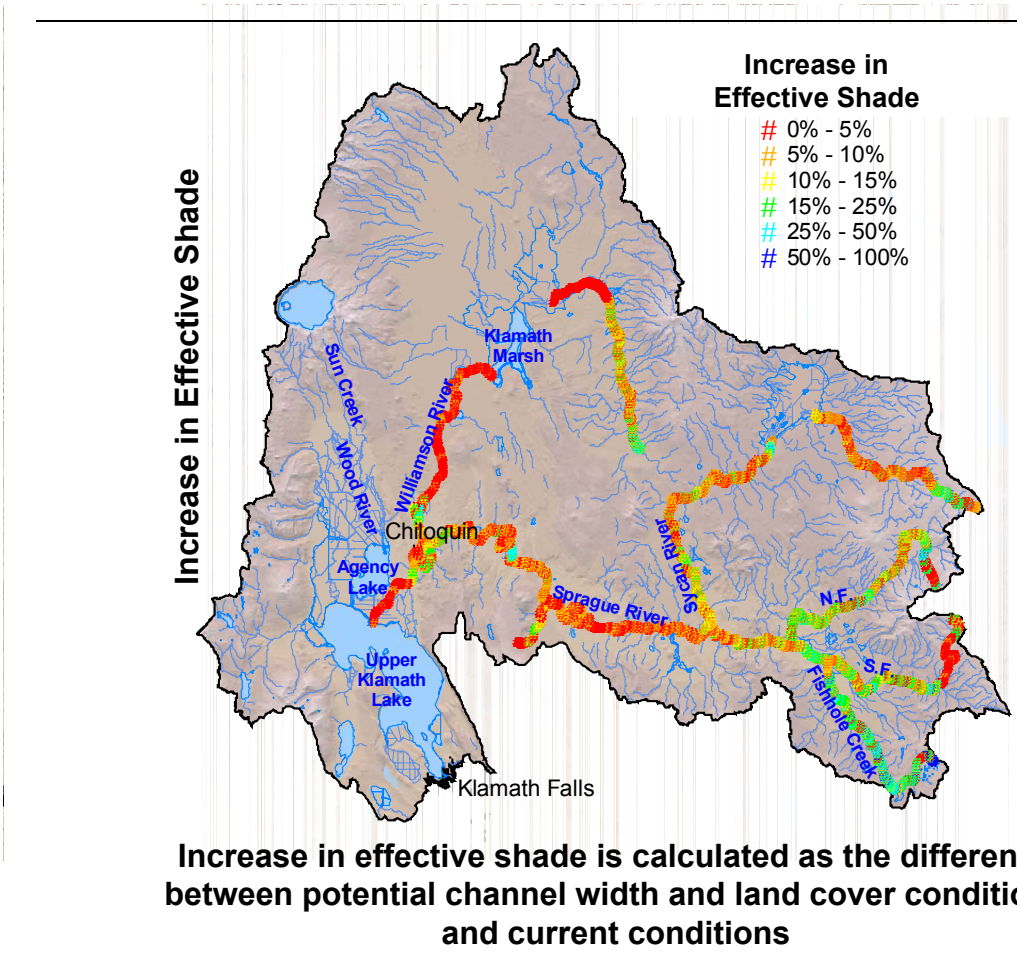


Figure 4-6. *Simulated increase in effective shade – the difference between potential channel width and land cover conditions and current conditions (July to August period).*

4.2 Effective Shade

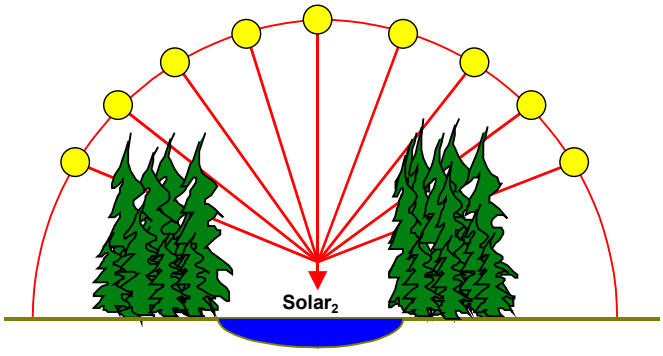
4.2.1 Overview - Description of Shading Processes

Stream surface shade is an important parameter that controls the stream heating derived from solar radiation. Recall that solar radiation has the potential to be the largest heat transfer mechanism in a stream system. Human activities can degrade near stream land cover and/or channel morphology, and in turn, decrease effective shade. It follows that human caused reductions in stream surface shade have the potential to cause significant increases in heat delivery to a stream system. Stream shade levels can also serve as an indicator of near stream land cover and channel morphology condition. For these reasons, stream shade is a focus of this analytical effort.

In the Northern Hemisphere, the earth tilts on its axis toward the sun during summertime months allowing longer day length and higher solar altitude, both of which are functions of solar declination (i.e., a measure of the earth's tilt toward the sun). Geographic position (i.e., latitude and longitude) fixes the stream to a position on the globe, while aspect provides the stream/riparian orientation. Near stream land cover height, width and density describe the physical barriers between the stream and sun that can attenuate and scatter incoming solar radiation (i.e., produce shade). The solar position has a vertical component (i.e., solar altitude) and a horizontal component (i.e., solar azimuth) that are both functions of time/date (i.e., solar declination) and the earth's rotation (i.e., hour angle measured as 15^{o} per hour). While the interaction of these shade variables may seem complex, the mathematics that describes them is relatively straightforward geometry. Using solar tables or mathematical simulations, the *potential daily solar load* can be quantified. The *measured solar load* at the stream surface can easily be measured with a Solar Pathfinder© or estimated using mathematical shade simulation computer programs (Boyd, 1996 and Park, 1993).

Effective Shade Defined

$Solar_1$ – Potential daily direct beam solar radiation load adjusted for julian day, solar altitude, solar azimuth and site elevation.



$$\text{Effective Shade} = \frac{(Solar_1 - Solar_2)}{Solar_1}$$

Where,

$Solar_1$: Potential Daily Direct Beam Solar Radiation Load
$Solar_2$: Daily Direct Beam Solar Radiation Load Received at the Stream Surface

***Figure 4-6**. Definition of effective shade*

Geometric Relationship that Influence Shade Production

Solar Altitude and **Solar Azimuth** are two basic measurements of the sun's position. When a stream's orientation, geographic position, riparian condition and solar position are known, shading characteristics can be simulated.

Solar Altitude measures the vertical component of the sun's position
Solar Azimuth measures the horizontal component of the sun's position

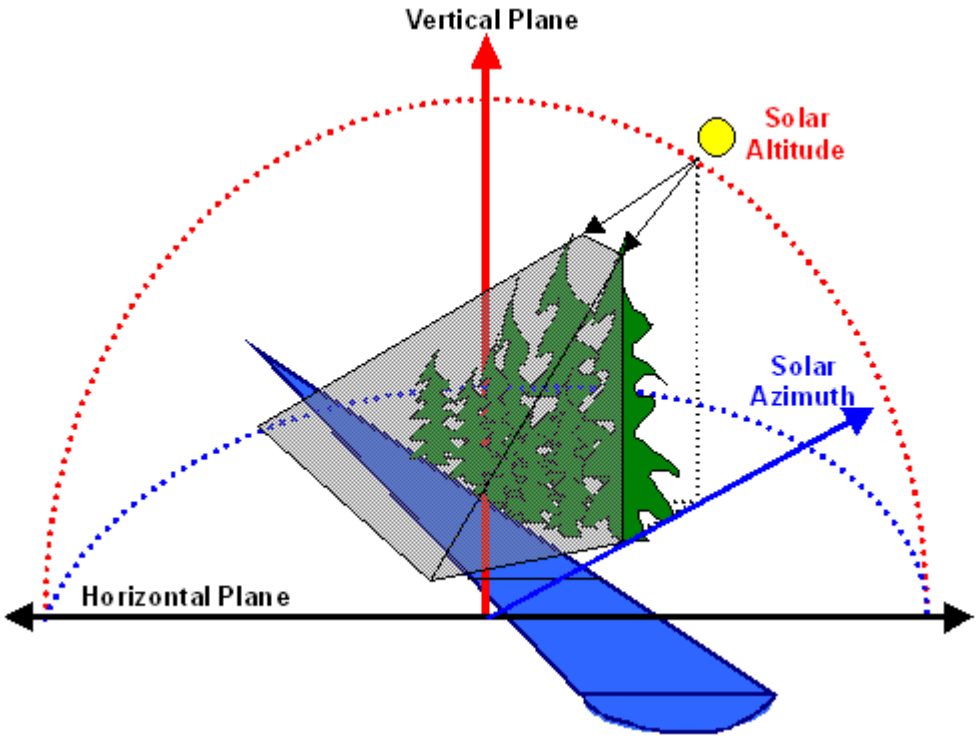


***Figure 4-7**. Parameters that affect shade and geometric relationships*

Table 4.1. Factors that Influence Stream Surface Shade

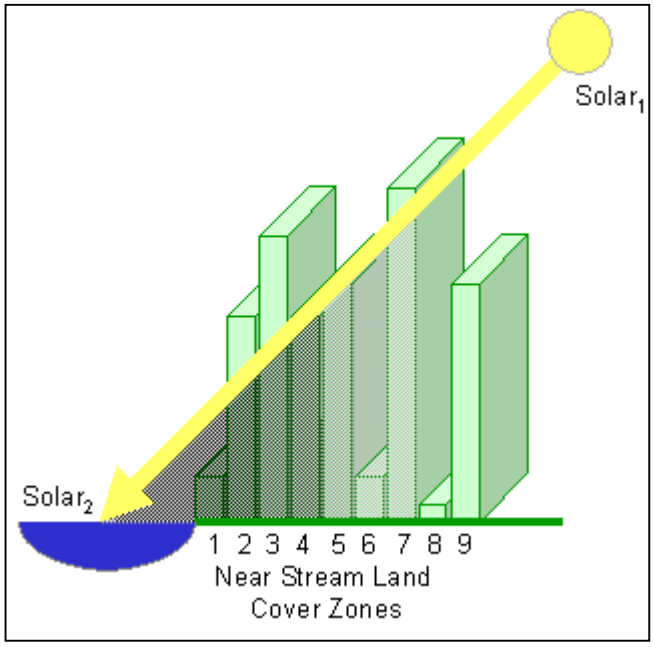
Blue – Not Influenced by Human Activities
Red - Influenced by Human Activities

Description	***Parameter***
Season/Time	Date/Time
Stream Characteristics	Aspect, Channel Width
Geographic Position	Latitude, Longitude
Vegetative Characteristics	Near Stream Land cover Height, Width, Density
Solar Position	Solar Altitude, Solar Azimuth

4.2.2 Effective Shade Simulation Methodology

Using computer software developed by ODEQ[22], stream surface shade can be simulated at a landscape scale. Topographic shade angle, channel morphology and land cover derived spatial data sets serve as high resolution input data. Stream surface shade production is a function of geometric relationships between the sun's position and topography, near stream land cover and channel features. For any given location, the sun's position is a function of time (i.e. season and time of day). Provided an accurate location description (i.e. latitude and longitude), the exact position of the sun for any given time can be easily simulated.

A vector between the sun and the stream can then be calculated. Topographic, land cover and/or stream channel features that obstruct the sun → stream vector create shade. Shade produced by topographic features and/or channel banks completely attenuates direct beam solar radiation. The shading algorithms mimic the travel direction of a photon from the sun to the stream. The first potential barrier to a photon is a topographic feature. If the sun angle is greater than that of topographic features, then the stream is not shaded from surrounding topography. The direct beam is then routed to the top of the land cover boundaries.



Land cover is broken into nine consecutive zones, each is fifteen feet in width, and located in the transverse direction. The direct beam is routed through the vegetation zones, staring at the outer zone 9. Each land cover height is checked to see if it intersects the sun → stream vector. If it does, then the attenuation of direct beam solar radiation caused by the land cover zone occurs as a function of a light extinction coefficient and the path length through the land cover zone. Path length through the land cover zone is a function of zone width, stream aspect, solar altitude and solar azimuth. Attenuation is calculated using Beer's Law (Oke, 1978). Direct beam radiant energy that passes through a land cover zone is then routed to the next inner land cover zone and the process is repeated. Once through all nine land cover zones, remaining direct beam solar radiation is routed to the stream surface. Diffuse solar radiation filters through the canopy and is attenuated as a function of canopy opening. If only the portion of the stream surface is shaded, while the remaining portion is exposed to direct beam solar radiation, the land cover attenuated solar flux is used for the shaded portion, and an unattenuated solar flux is used for the non-shaded portion. At the stream surface, the remaining direct beam and the received diffuse solar radiation are summed and become the solar load received at the top of the stream surface ($Solar_2$).

A portion of solar radiation is reflected off the stream surface as a function of the solar angle, while the remaining portion enters the water column. The water column solar path length is a function of the solar angle and water depth. The portion of the received direct beam solar radiation absorbed by the water column is a function of water column path length and the transmissivity of the water column. The remaining solar radiation is received at the stream bed, where a portion is absorbed as a function of solar angle and literature values for reflectivity

[22] ODEQ has developed and maintains a computer application called Shade-a-lator that can predict stream surface shade at a user defined spatial scales.

properties of quartz (Beschta and Weatherred, 1984). Heat absorbed by the streambed will cause differential heating and start conducting back to the water column. The remaining portion of solar direct beam radiation is reflected off the stream bed and travels towards the surface of the stream, where again there is absorption of remain solar radiation in the water column as a function of path length and stream transmissivity.

Below are the steps used for calculating effective shade. Effective shade is a ratio of the received solar load to the total potential solar load. Both total potential and received solar radiation is calculated for any given day at a 10-minute time step for each stream data node.

1. Calculate solar position as a function of time and in relation to a defined location. Variables calculated are:
   - solar altitude
   - solar zenith
   - solar declination
   - solar azimuth

2. Calculate direct beam and diffuse beam solar radiation received at the top of the land cover boundary. Variables calculated are:
   - air mass thickness
   - air mass transmissivity
   - topographic shade angle
   - solar load received at edge of atmosphere
   - direct beam solar radiation received at top of land cover boundary
   - diffuse solar radiation received at top of land cover boundary
   - potential solar load

3. Calculate direct beam and diffuse beam solar radiation received at the top of the stream surface. Direct beam solar radiation is routed through all land cover zones (i.e. 9 zones every 15 feet starting at the furthest from the stream channel). Diffuse solar radiation is proportional to the canopy opening. Variables calculated are:
   - percent canopy opening
   - land cover transmissivity
   - path length through land cover
   - direct beam solar radiation received at top of stream
   - diffuse solar radiation received at top of stream
   - shadow extension into the stream channel
   - portion of the stream channel shaded (0 to 1)
   - total solar load received at top of stream

4. Calculate solar radiation absorbed in the water column and streambed. Variables calculated are:
   - water surface reflectivity
   - water column transmissivity
   - streambed reflectivity
   - path length through water column
   - total solar load received by water column

5. Calculate effective shade. Variables calculated are:
   - $Solar_1$ = daily sum of potential solar load
   - $Solar_2$ = daily sum of total solar load received at top of water column
   - Effective Shade = ($Solar_1$ - $Solar_2$) / $Solar_1$

4.2.2.1 Effective Shade Simulation Period and Extent

The effective shade analysis was conducted with data input sampling and a computation rate every 100 feet along stream segments. The effective shade model is calibrated to analyze and predict stream temperature for narrow periods of time as a function of Julian Day, however other periods can be simulated. Periods of simulation occurred in early to mid August and output data is reliable for the July through August period. Simulations were performed for a total of 321.8 river miles in the Sprague River and Williamson River subbasins. **Table 4-2** lists the spatial extent and simulation period for by river system.

Table 4-2. Effective Shade Simulation Periods and Extent

River/Stream	Simulation Period	Simulation Extent
Williamson River[23]	Late July/Early August	RM 0.0 to 41.5, 56.4 to 86.23
Sycan River[24]	Late July/Early August	RM 0.0 to 37.8, 44.0 to 71.5
North Fork Sprague River	Late July/Early August	RM 0.0 to 34.2
South Fork Sprague River	Late July/Early August	RM 0.0 to 32.0
Sprague River	Late July/Early August	RM 0.0 to 84.6
Fishhole Creek	Late July/Early August	RM 0.0 to 26.8
Trout Creek	Late July/Early August	RM 0.0 to 7.6
		Total Simulation Extent 321.8 river miles

4.2.2.2 Simulated Effective Shade Scenarios

Once effective shade models are calibrated, potential channel width and land cover scenarios are simulated. The combinations of potential channel width and near stream land cover are simulated together to maximize the benefits of potential land cover physical properties and channel width reductions related to shade production. A range of effective shade is developed in these scenarios because a high and low range of potential land cover was used as model input.

Shade Scenario 1: Current Condition

Shade Scenario 2: Potential Channel Width
Potential Near Stream Land Cover - High Range
All other inputs remain unchanged

Shade Scenario 3: Potential Channel Width
Potential Near Stream Land Cover - Low Range
All other inputs remain unchanged

4.2.2.2 Validation - Effective Shade Simulation Accuracy

Effective shade simulation validation was conducted by comparing simulated results with ground level measured effective shade values. Solar pathfinder data was used to collect all ground level data. A total of 346 discrete samples were collected in the Sprague River and Williamson River subbasins. Shade simulations have a standard error of 7.7% when compared to these values. The correlation coefficient between measured and simulated values is high (i.e. $R^2 = 0.90$). The statistical significance of model output is roughly 8% effective shade.

[23] Effective shade was not sampled in Klamath Marsh (Williamson River - river miles 41.5 to 56.4).

[24] Effective shade was not sampled in Sycan Marsh (Sycan River- river miles 37.8 to 44.0).

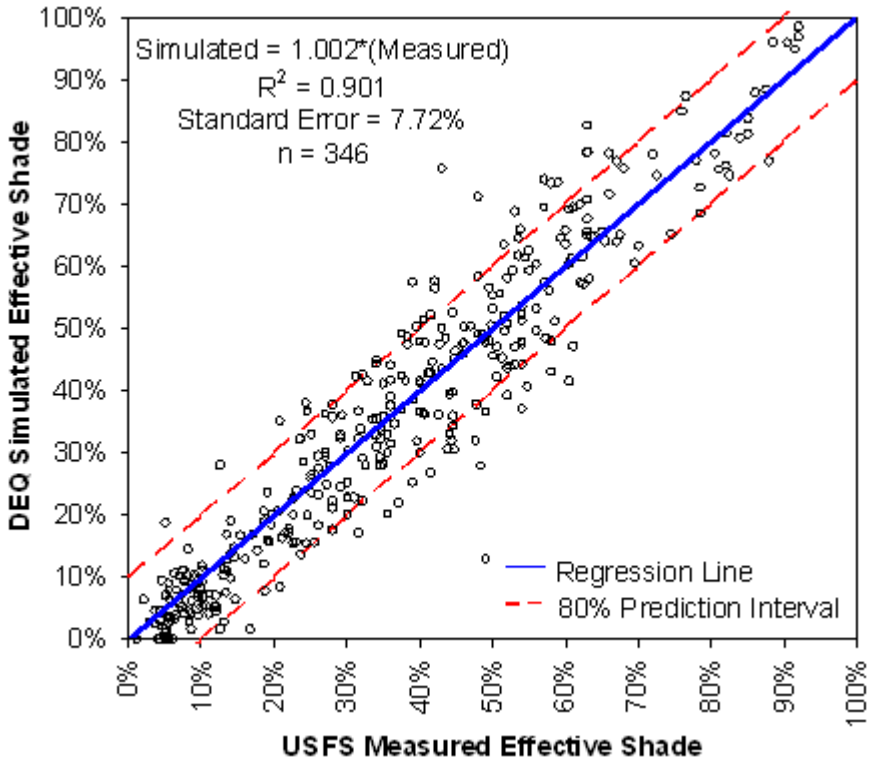


***Figure 4-8**. Simulated effective shade compared to ground level measured effective shade.*

4.2.3 Effective Shade and Solar Heat Flux Simulations

4.2.3.1 Site Specific Effective Shade Simulations

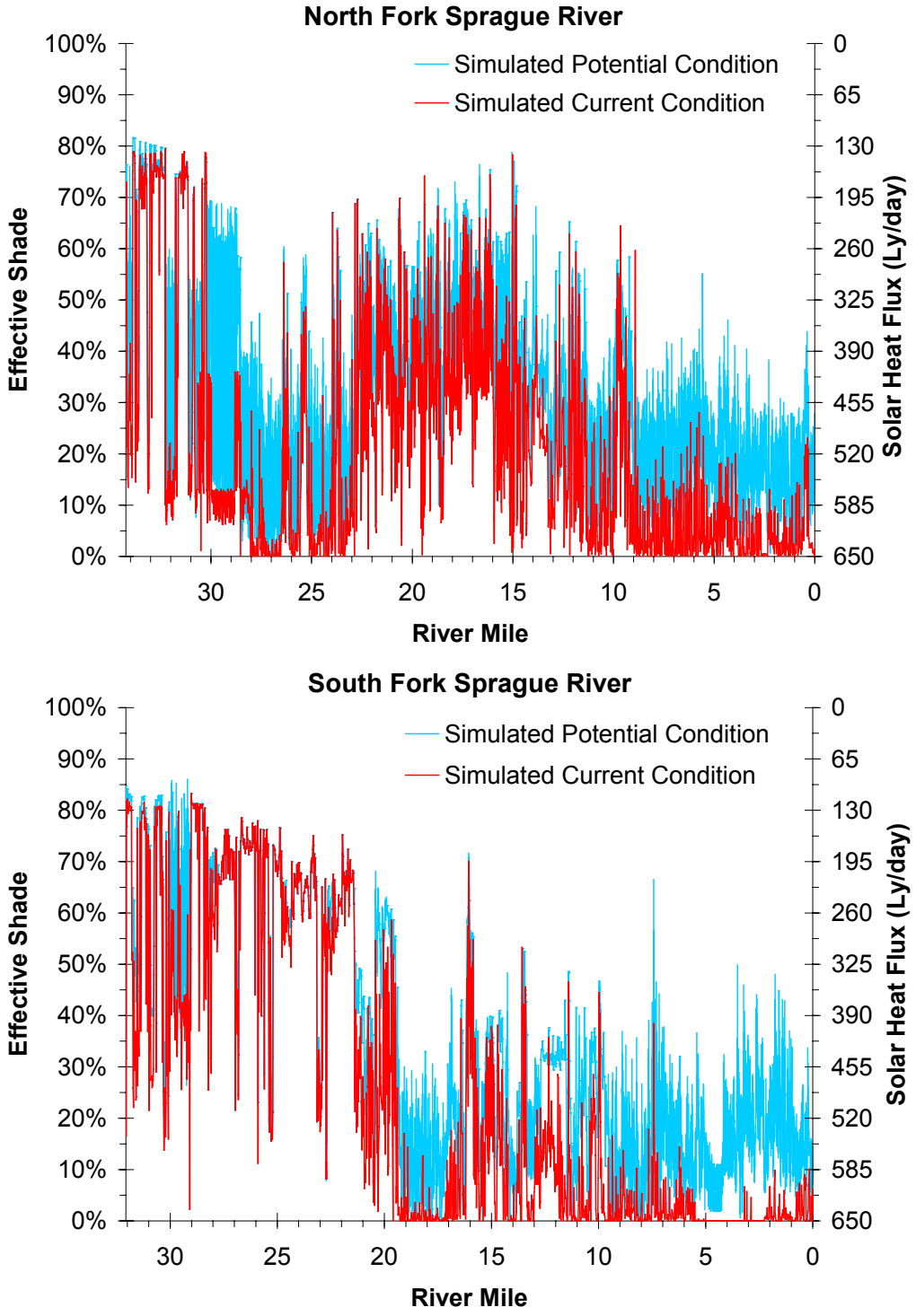


***Figure 4-9**. Simulated effective shade data - Current condition and Potential Condition.*

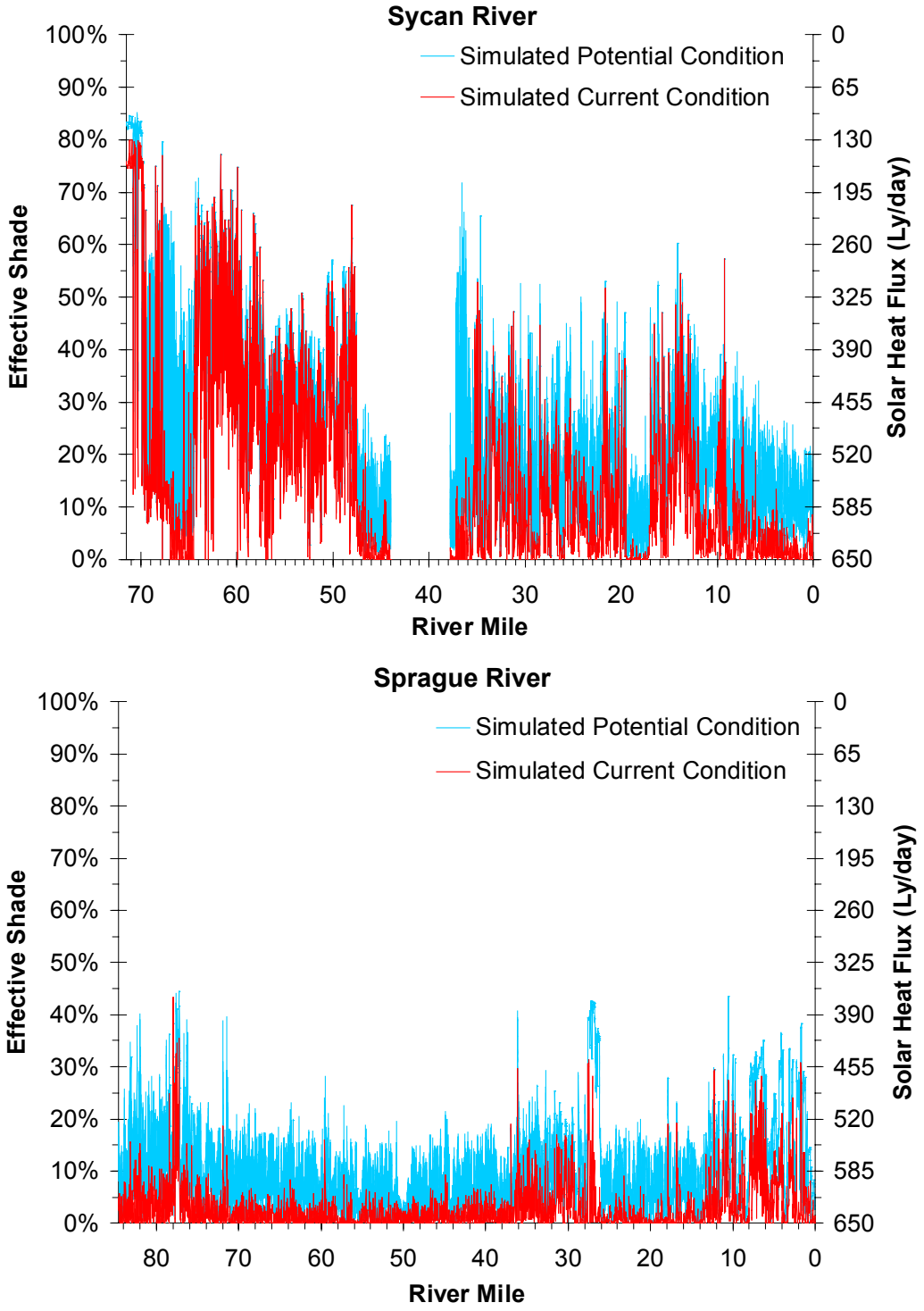


Figure 4-9 (continued). *Simulated effective shade data - Current condition and Potential Condition.*

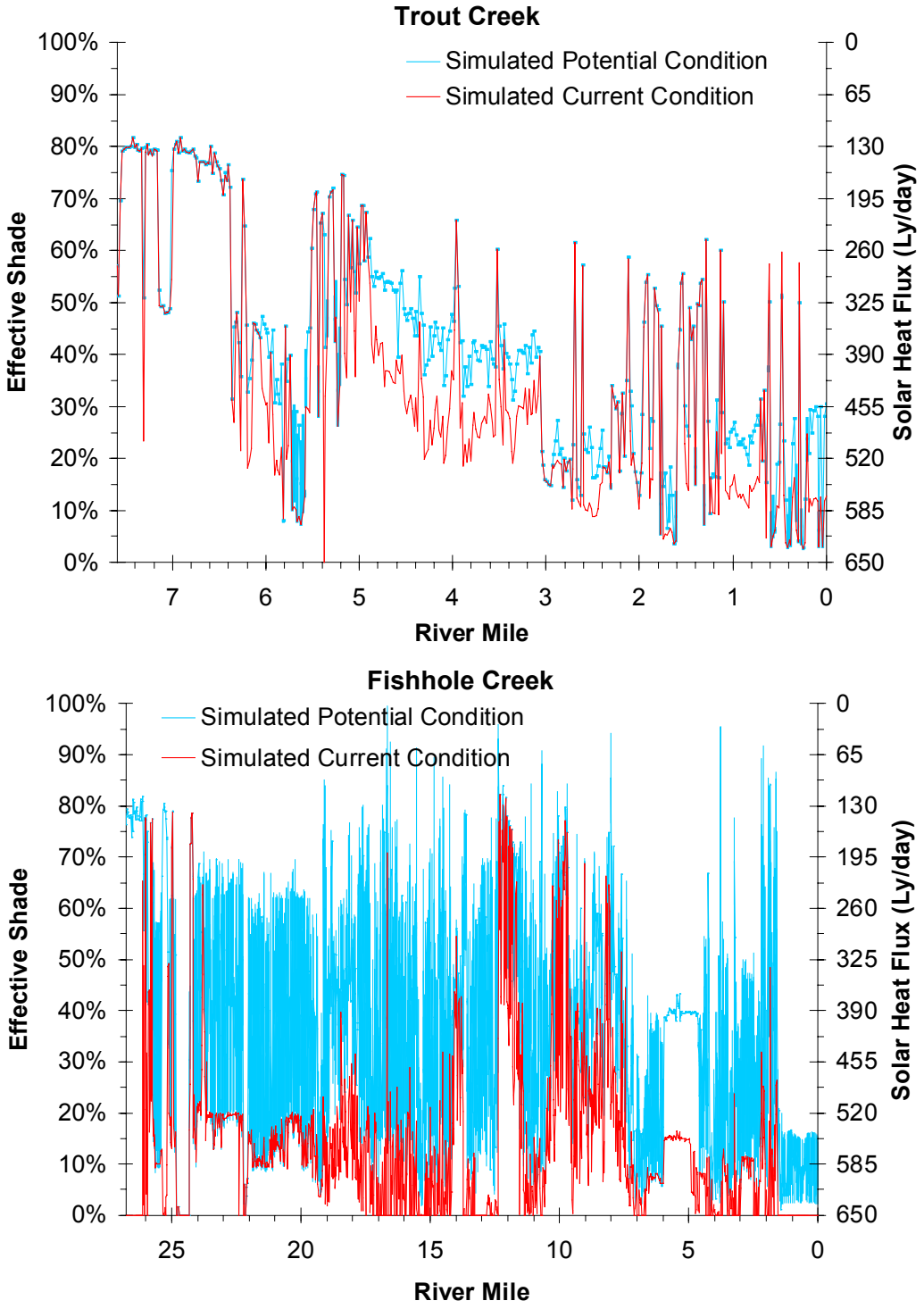


Figure 4-9 (continued). *Simulated effective shade data - Current condition and Potential Condition.*

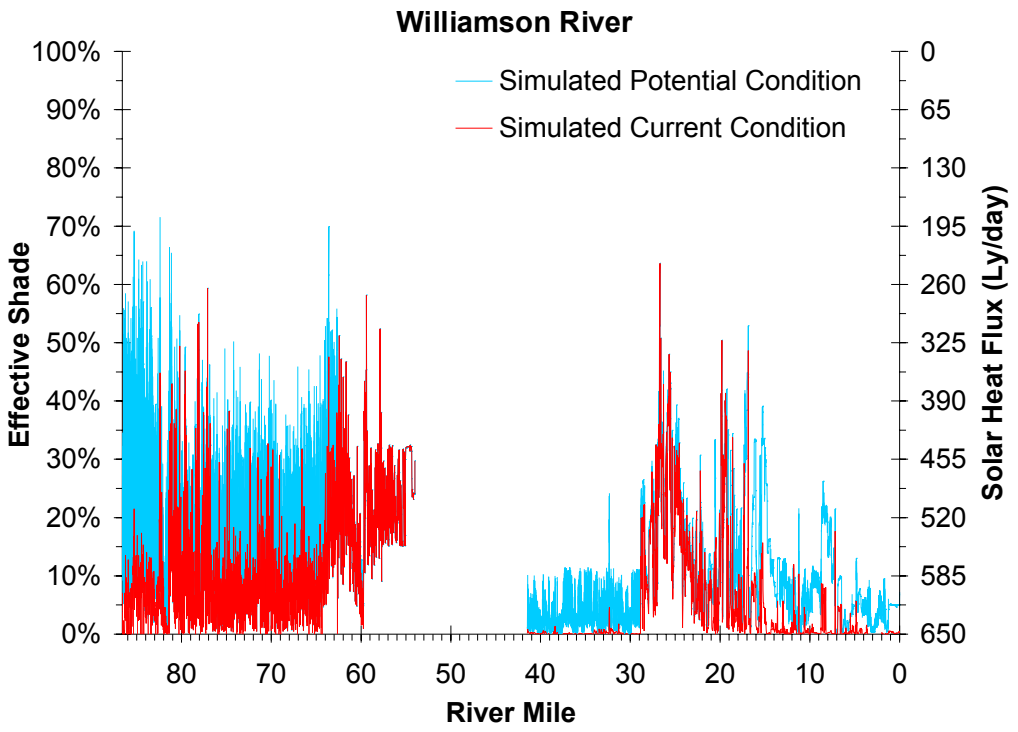


***Figure 4-9 (continued)**. Simulated effective shade data - Current condition and Potential Condition.*

For the sake of comparison, average effective shade values are presented in **Figure 4-10**. Several observations can be made from the simulations results. Effective shade levels are generally low in the Upper Klamath Lake drainage, in both the current and system potential conditions. Petersen et al. (1999) points out "the importance of even small amounts of shade in moderating stream heating." Increases in stream shade will directly reduce solar radiation and reduce both daily maximum stream temperatures and daily fluctuation of stream temperature. This holds true when shade levels are increased from any level. So even minor increases in shade will reduce the heat transfer to the stream system.

Another observation is that lower river reaches have less shade than upper reaches. This is the result of large channel width and the prevalence of land cover types that are shorter. Large channels combined with shorter land cover limits the amount of shade received. The opposite is also observed in the average shade data. Higher shade levels occur in upper reaches with narrower channels and that generally have taller growing land cover types.

The largest disparity between the two conditions (i.e. current condition and the system potential condition) occurs in Fishhole Creek and the North and South Fork of the Sprague Rivers. This does not imply that these systems are the most impaired, but instead, highlights that due to the relatively small stream size, that these systems have higher shade potentials. The larger stream systems, such as the Sycan, Sprague and Lower Williamson Rivers have a smaller difference between current and potential shade conditions (see **Figure 4-11**). It should be emphasized that even small increases in stream shade can have a significant thermal effect (Petersen et al., 1999).

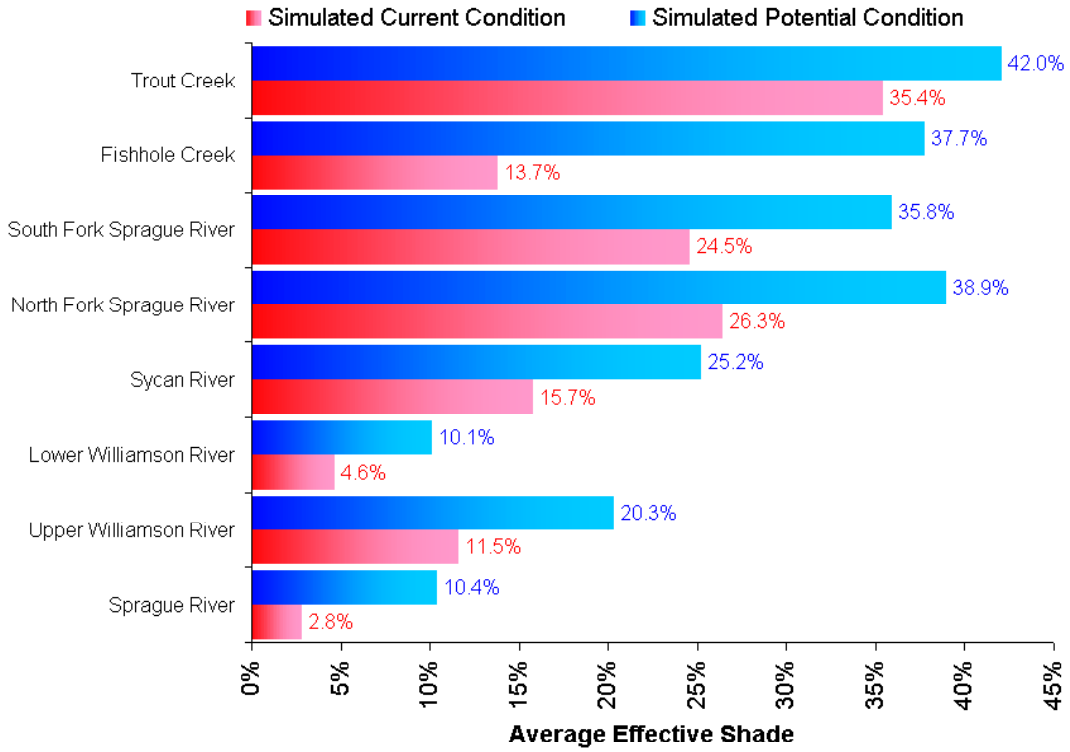


***Figure 4-10**. Average simulated effective shade data - Current condition and system potential condition.*

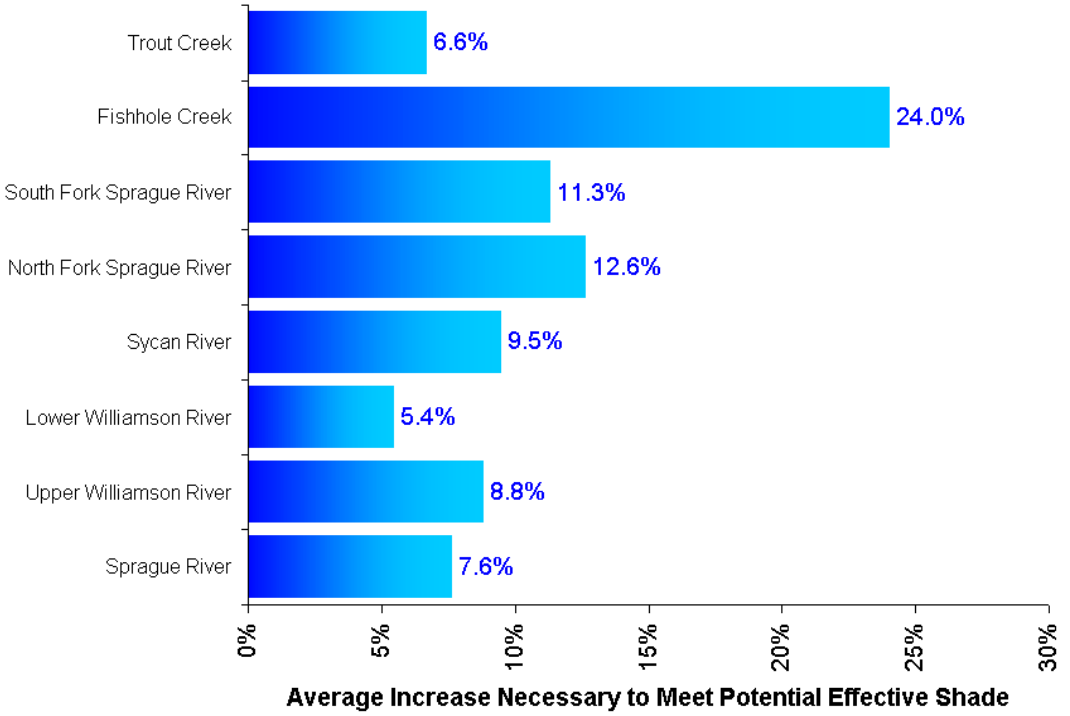


***Figure 4-11**. The percent increase in effective shade levels from the current condition to the system potential condition.*

4.2.4 Total Daily Solar Heat Load Analysis

Solar heating is established as a primary pollutant in stream heating processes. The calculation of the overall heat load received by the stream system from solar radiation yields the nonpoint sources of solar heat for the total stream system as well as for each stream/river. The total daily solar heat load is the cumulative solar heat received by a stream over one day during the critical period (i.e. July/August period). For the purposes of this analytical effort, the total solar heat load is the sum of the products of the daily solar heat flux and surface area of exposure for each stream reach (i.e. for each stream data node every 100 ft).

$$H_{solar} = \sum \left(\Phi_{solar} \cdot A_y \right) = \sum \left(\Phi_{solar} \cdot W_{wetted} \cdot dx \right)$$

Background levels of solar heat estimate the portion of the total daily solar heat load that occurs when nonpoint sources of heat are minimized. The background condition is the system potential total daily solar heat load (i.e. where anthropogenic nonpoint sources are minimized) and is calculated by substituting the system potential daily solar flux and the potential wetted width into the equation above. In this fashion, the total daily solar load is calculated for both the current condition (H_{solar}) and the system potential condition ($H_{solar}^{Background}$). With the background portion of the total daily solar load accounted for, the remaining portion can be attributed to anthropogenic nonpoint sources. Therefore, the anthropogenic nonpoint source total daily solar load is the difference between the total daily solar load and the background total daily solar load. Derived total daily solar loads for background sources and anthropogenic nonpoint sources are presented in **Figure 4-12**.

$$H_{solar}^{NPS} = H_{solar} - H_{solar}^{Background}$$

where,

A_y : Stream surface area unique to each stream segment (cm^2)

Dx: Stream segment length and distance step in the methodology (cm)

Φ_{solar} : Solar heat flux for unique to each stream segment (kcal cm^{-2} day^{-1})

H_{solar} : Total daily solar heat load delivered to the stream (kcal day^{-1})

H_{solar}^{NPS} : Portion of the total daily solar heat load delivered to the stream that originates from nonpoint sources of pollution (kcal day^{-1})

$H_{solar}^{Background}$: Portion of the total daily solar heat load delivered to the stream that originates from background sources of pollution that are not affected by human activities (kcal day^{-1})

W_{wetted}: Wetted width unique to each stream segment (cm)

Roughly one quarter of the solar loading that occurs in the Williamson and Sprague River systems, including major tributaries, is from anthropogenic nonpoint sources, while the remaining three quarters of the total daily solar load originates from background sources (see **Figure 4-12**).

Roughly 72% of the anthropogenic nonpoint source solar heat load originates in the Williamson and Sprague mainstem reaches. The remaining 28% of the anthropogenic nonpoint sources solar heat load is derived from tributary stream reaches (see **Figure 4-13**). It should be noted, however, that the majority of anthropogenic nonpoint solar heat sources occur in the lower gradient heavily impacted reaches of both the mainstem and tributary reaches.

The Sprague River is a major source for anthropogenic solar heat, accounting for 41.5% of the nonpoint source solar load. The Williamson River is also a major contributor of anthropogenic

nonpoint solar heat, accounting for 29% of the nonpoint source loading. The Sycan River and and North Fork Sprague River account for 14% and 8% of the anthropogenic nonpoint source solar heat load, respectively. The South Fork, Fishhole Creek and Trout Creek contribute the least to the anthropogenic nonpoint solar heal load accounting for 4%, 2% and <1%, respectively (see **Figure 4-14**).

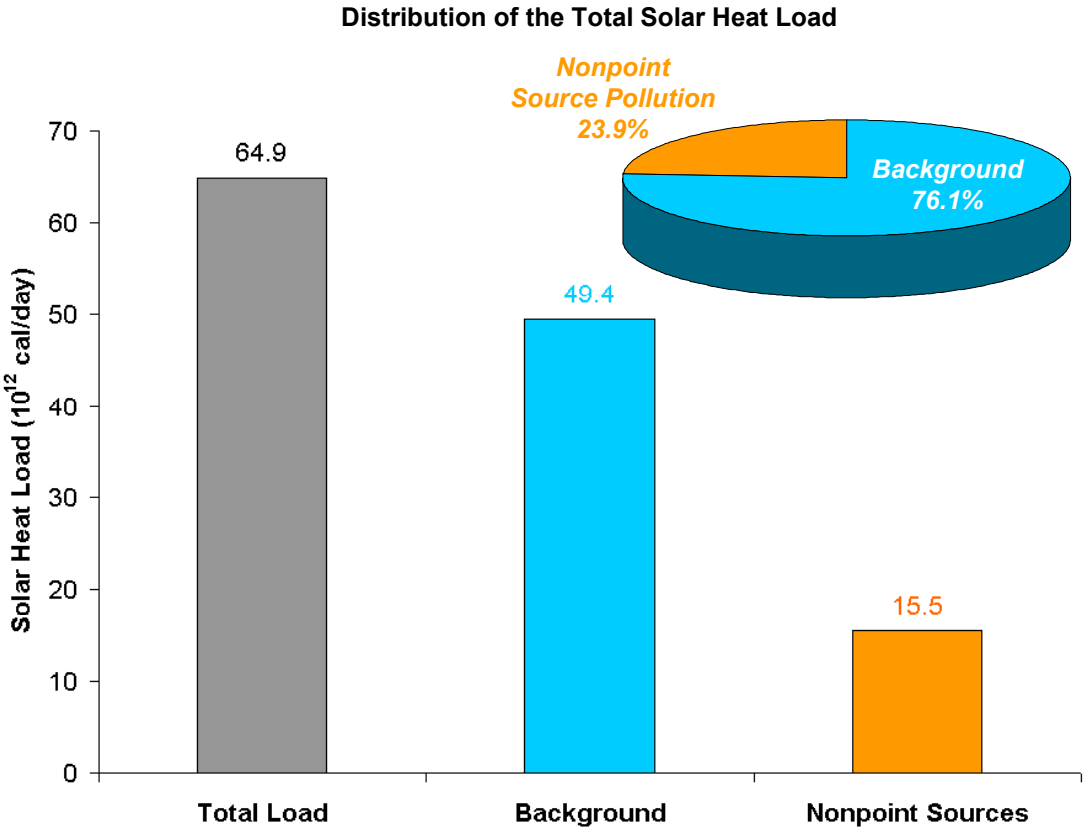


***Figure 4-12**. Total daily solar heat load derived as the sum of the products of the daily solar heat flux and wetted surface area. For the purposes of this analysis the total heat load is calculated from the simulated current condition. The background condition is calculated from the system potential channel width and land cover condition simulations (Scenarios #13 and #14). Recall that potential land cover has a high and low range. Solar heat flux output data is averaged for these two conditions to obtain an average potential heat load. The nonpoint source load is the difference between the current total daily solar load and the background total daily solar heat load.*

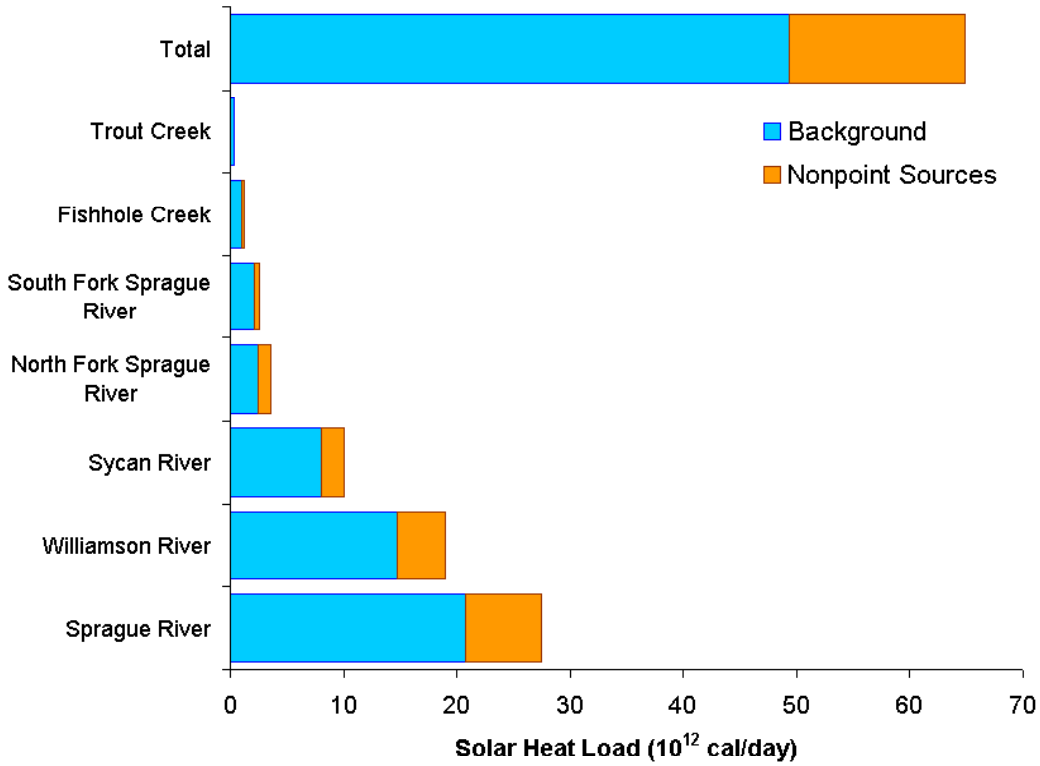


***Figure 4-13**. Distribution of the total solar heat load for anthropogenic nonpoint sources and background sources by stream/river system.*

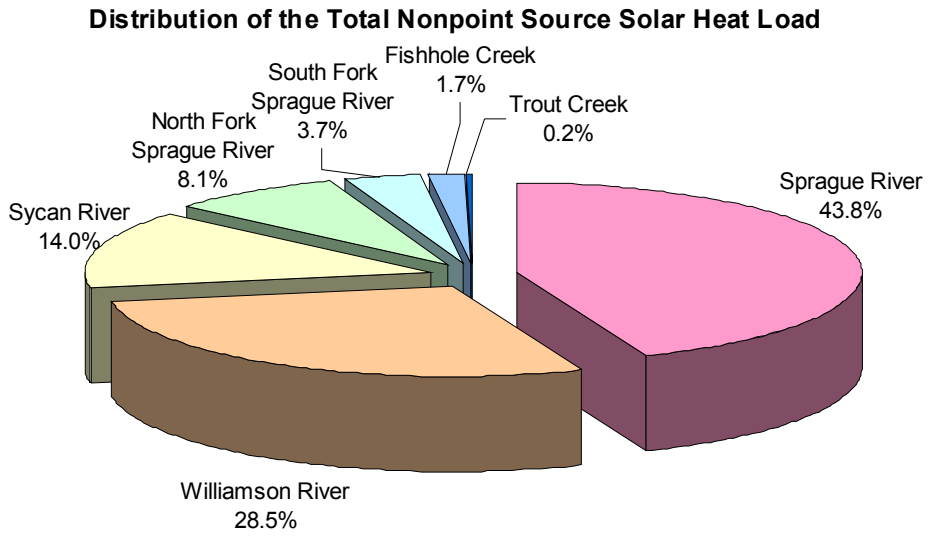


***Figure 4-14**. Distribution of the total anthropogenic nonpoint source solar heat load.*

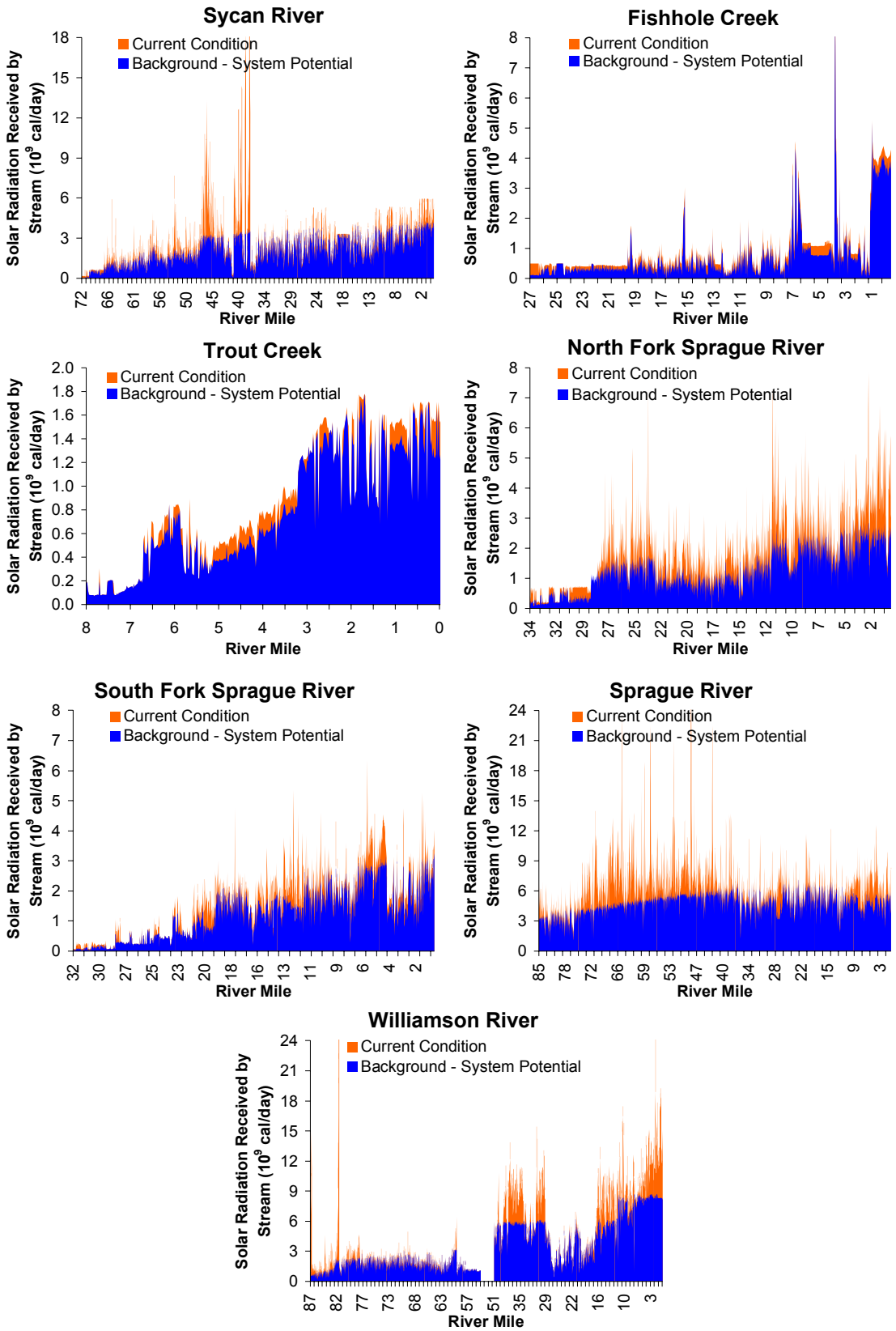


***Figure 4-15**. Total daily solar heat loads derived from solar heat flux and wetted surface area.*

4.2.5 Effective Shade Curve Development

Effective shade curves are designed to display effective shade levels for a specific land cover type as a function of channel width. These shade curves are intended to provide effective shade targets where site-specific effective shade simulations have not been completed. For a list of stream segments where effective shade simulations have been performed reference **Section 4.2.2.1 Effective Shade Simulation Period and Extent.** Effective shade curves presented in this document are developed for the Upper Klamath Lake drainage location (i.e. latitude and longitude) and are accurate for the critical time period (i.e. July/August). Stream aspect is also considered in the shade curve methodology.

The land cover types used for development of the shade curves are those developed as the potential land cover types: large conifer, large hardwood, large conifer/hardwood mix, shrub and graminoid/forb. For more information regarding the potential land cover types reference **Section 3.5.3 Near Stream Land Cover - Potential Condition Development.** Land cover physical dimensions for height and density are listed on the shade curves. Determination of appropriate potential land cover types is the responsibility of the designated management agencies and private citizens.

Channel width targets can be determined from regional curves developed in **Section 3.4.4 Channel Width Assessment.** Recall that potential channel width is a function of potential Rosgen stream type, width to depth ratio and drainage area. Determination of the appropriate potential Rosgen stream type is the responsibility of the designated management agencies and private citizens.

Figures 4-16 to **4-20** display shade curves for the potential land cover types. The practical use of these shade curves may seem complex. Indeed, it can be. However, this methodology provides land cover, channel width and effective shade targets for the remaining portions of the Williamson and Sprague River subbasins. The shade curves also demonstrate the relationship between land cover physical properties, channel width and stream aspect.

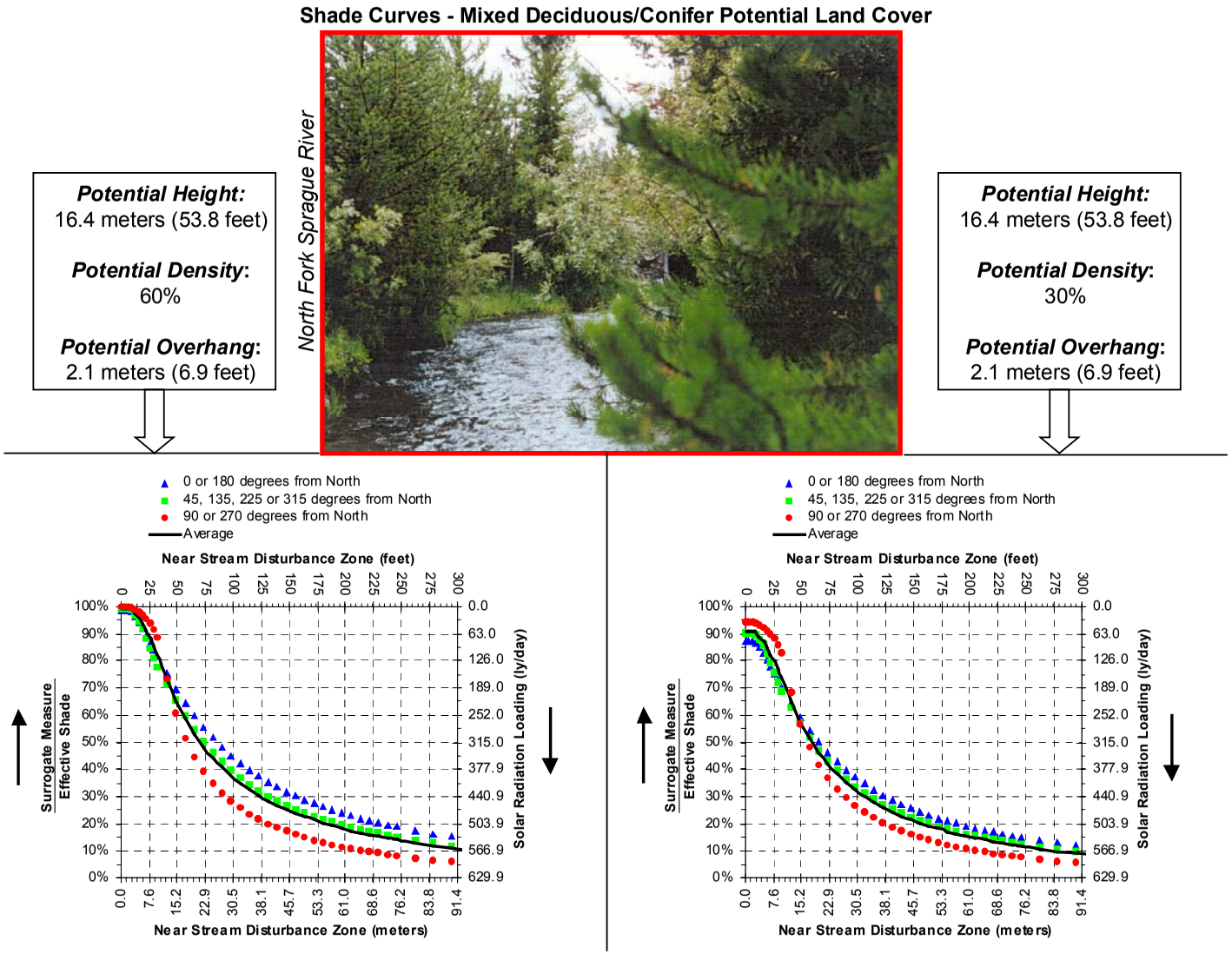


Figure 4-16. *Effective shade curves for the mixed hardwood and conifer land cover type.*

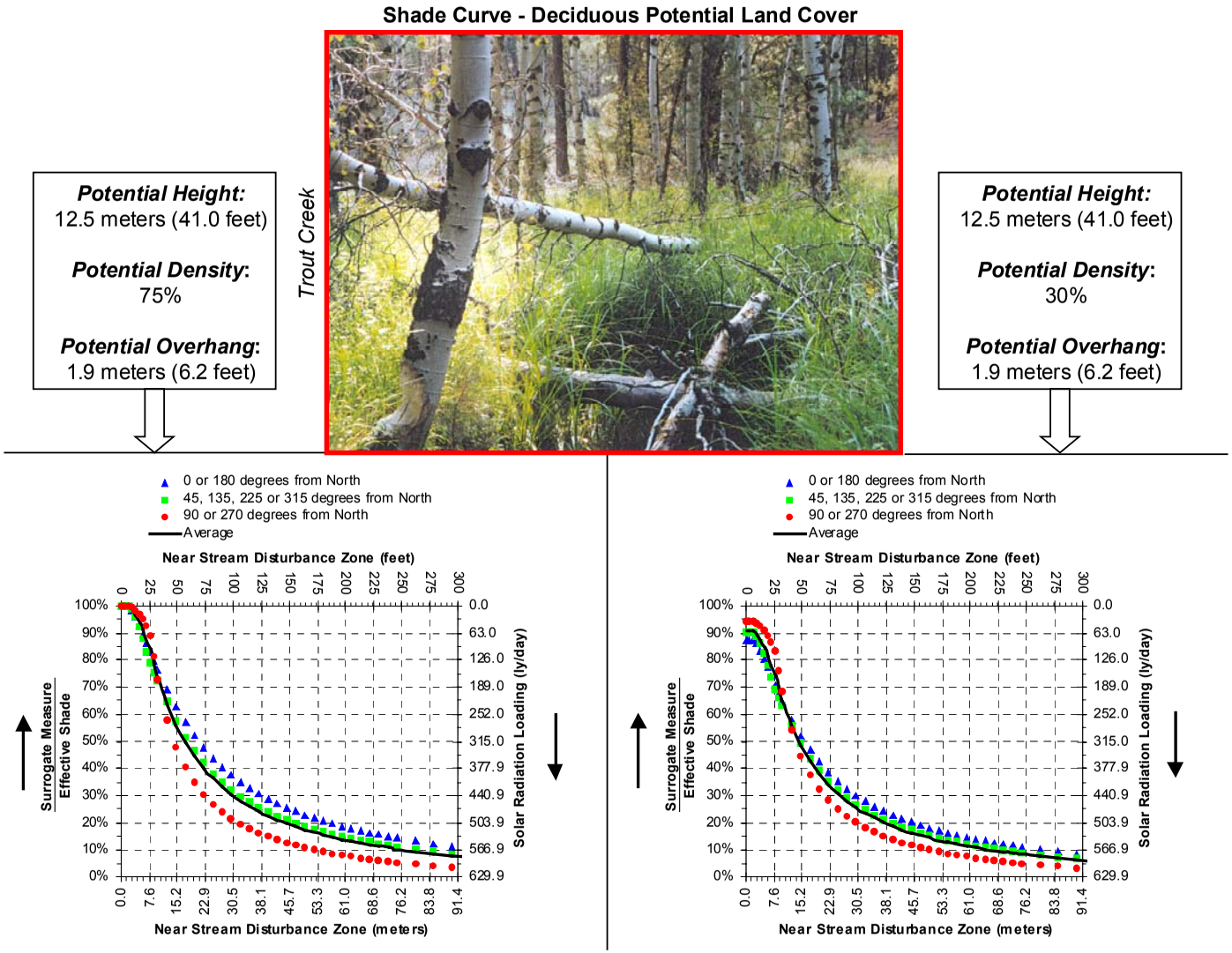


Figure 4-17. *Effective shade curves for the deciduous/hardwood land cover type.*

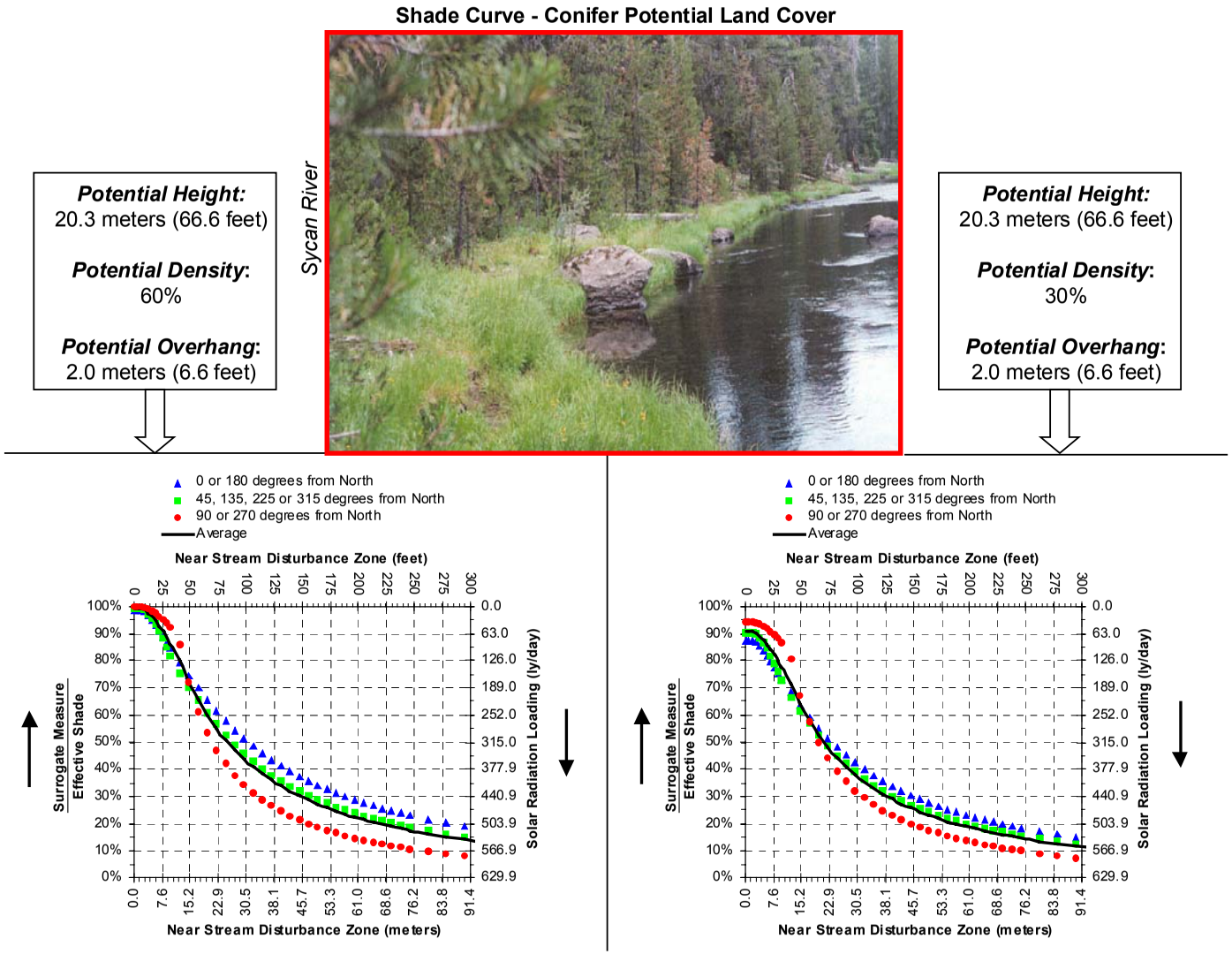


Figure 4-18. *Effective shade curves for the conifer land cover type.*

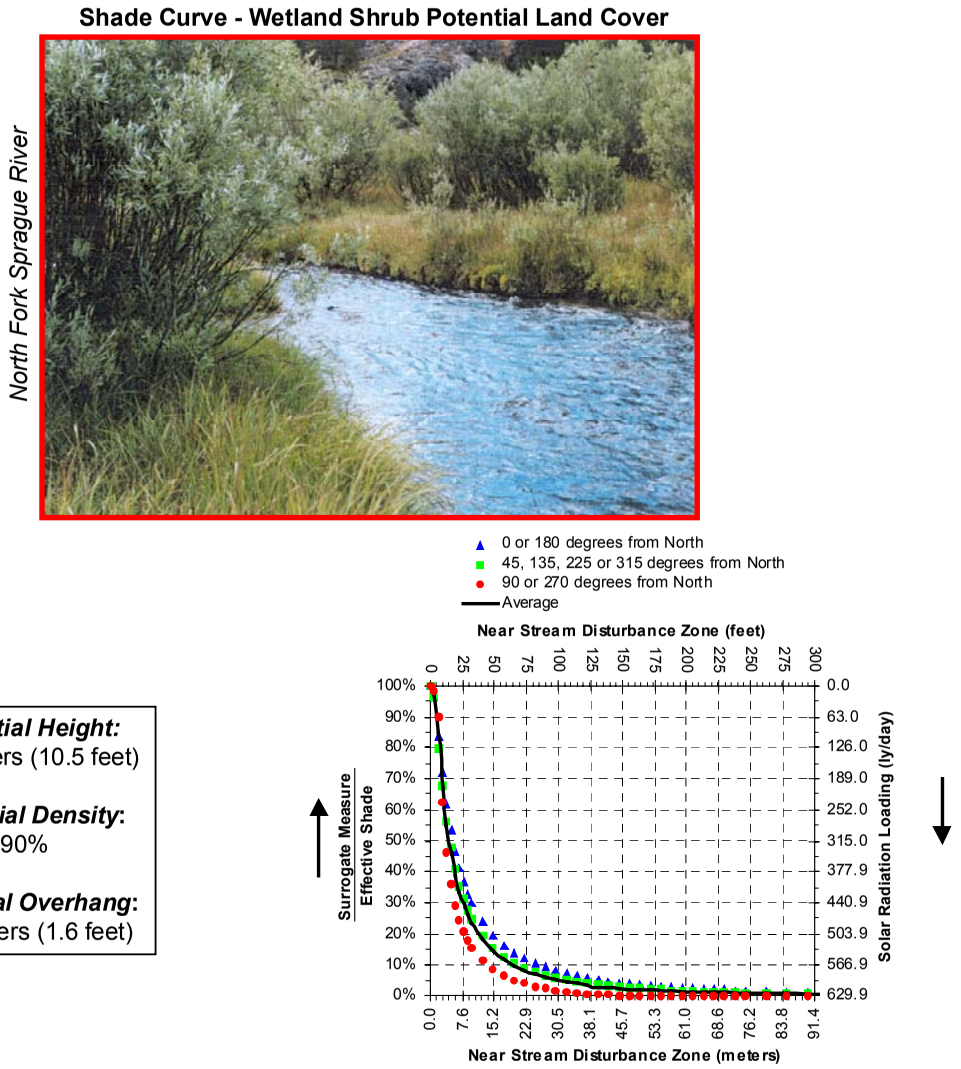


Figure 4-19. *Effective shade curves for the shrub land cover type.*

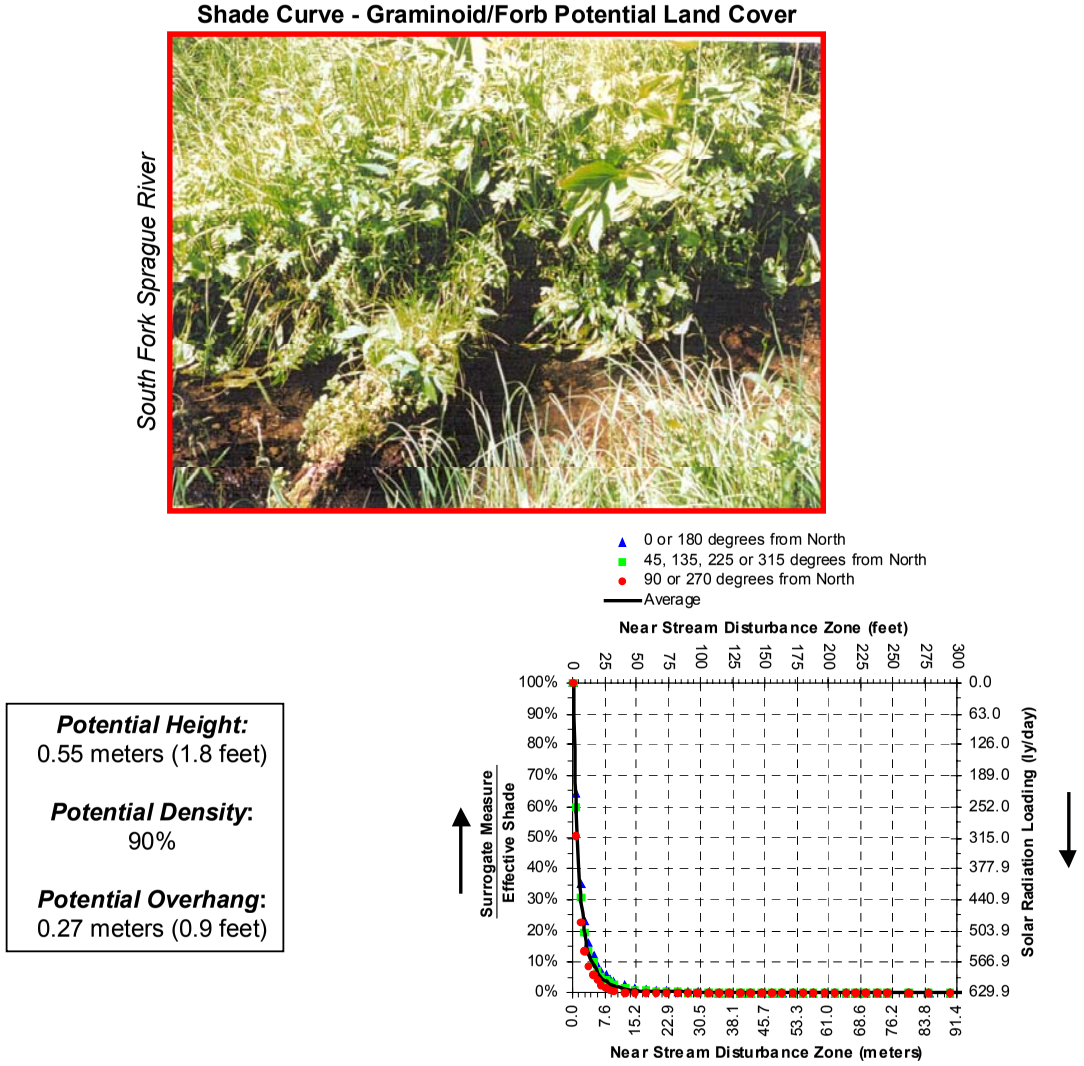


Figure 4-20. *Effective shade curves for the graminoid/forb land cover type.*

4.3 Stream Temperature Simulations

4.3.1 Stream Temperature Simulation Methodology

Water temperature change is a function of the heat transfer in a discrete volume. Similarly, heat is a measure of stream temperature change, based on the properties of water. By excluding constants, it can be demonstrated that temperature change is proportional to heat and inversely proportional to river flow rates.

Calculation of Heat,

$$H = \Delta T_R \cdot M_R \cdot c_w = \Delta T_R \cdot (Q_R \cdot t \cdot \rho_w) \cdot c_w$$

Calculation of Water Temperature Change,

$$\Delta T_R = \frac{H}{M_R \cdot c_w} = \frac{H}{(Q_R \cdot t \cdot \rho_w) \cdot c_w}$$

Excluding constants, water temperature change is a function of heat and river flow,

$$\Delta T_R \propto H, \ \frac{1}{Q_R}$$

where,

Metric units are used in all computations

ΔT_R : Change in river temperature (^oC)

H : Heat (cal)

Q_R : Flow rate (cms)

M_R : Mass of river volume (kg)

c_w : Specific heat of water $\left(10^3 \frac{cal}{kg} = \frac{kcal}{kg}\right)$

ρ_w : Density of water $\left(10^3 \frac{kg}{m^3}\right)$

t : Duration (sec)

All heat transfer rates can be quantified as a flux, which implies heat transfer per a unit area per a unit time. For computational purposes this methodology relies on heat flux metric units.

$$\text{Heat Flux} = \frac{\text{Heat}}{\text{Area} \cdot \text{Time}} = \frac{cal}{cm^2 \cdot sec} = \frac{ly}{sec}$$

Water has a relatively high heat capacity ($c_w = 10^3$ cal kg^{-1} K^{-1}) (Satterlund and Adams 1992). Conceptually, water is a heat sink. Heat that is gained by the stream is retained and only slowly released back to the surrounding environment. Heat released from the stream to the surrounding environment is represented by a negative heat flux ($\Phi_{cooling}$). Heat delivered to the stream is a positive heat flux ($\Phi_{heating}$). Excluding mass transfer processes, heating periods occur when the net heat flux (Φ_{total}) is positive. Cooling periods occur when the net heat flux is negative.

$$\Phi_{total} = \Phi_{heating} + \Phi_{cooling}$$

4.3.1.1 Heat Transfer Processes

In general, the net heat flux experienced by all stream/river systems follows two cycles: a seasonal cycle and a diurnal cycle. In the Pacific Northwest, the seasonal net heat cycle experiences a maximum positive flux during summer months (July and August), while the minimum seasonal flux occurs in winter months (December and January). The diurnal net heat cycle experiences a daily maximum flux that occurs at or near the sun's zenith angle, while the daily minimum flux often occurs during the late night or the early morning. It should be noted, however, that meteorological conditions are variable. Cloud cover and precipitation seriously alter the heat relationships between the stream and its environment.

The ultimate source of heat to a stream system is solar radiation both diffuse and direct. Secondary sources of heat include longwave radiation (also referred to as thermal radiation) from the atmosphere and streamside vegetation, streambed conduction, and in some cases, groundwater exchange at the water-stream bed interface. Several processes dissipate heat at the air-water interface, namely: evaporation, convection and back radiation. Heat is acquired by the stream system when the flux of heat energy entering the stream is greater than the flux of heat energy leaving. The net heat flux provides the rate at which energy is gained or lost per unit area and is represented as the instantaneous summation of all heat energy components. The net heat flux (Φ_{total}) consists of several individual thermodynamic heat flux components, namely: solar radiation (Φ_{solar}), long-wave radiation ($\Phi_{longwave}$), conduction ($\Phi_{conduction}$), groundwater exchange ($\Phi_{groundwater}$) and evaporation ($\Phi_{evaporation}$) (Wunderlich, 1972; Jobson and Keefer, 1979; Beschta and Weatherred, 1984; Sinokrot and Stefan, 1993; Boyd, 1996). With the exception of solar radiation, which only delivers heat energy, these processes are capable of both introducing and removing heat from a stream. The instantaneous heat transfer rate experienced by the stream is the summation of the individual processes.

When a stream surface is exposed to midday solar radiation, large quantities of heat will be delivered to the stream system (Brown 1969, Beschta et al. 1987). Some of the incoming solar radiation will reflect off the stream surface, depending on the elevation of the sun. All solar radiation outside the visible spectrum (0.36μ to 0.76μ) is absorbed in the first meter below the stream surface and only visible light penetrates to greater depths (Wunderlich, 1972). Sellers (1965) reported that 50% of solar energy passing through the stream surface is absorbed in the first 10 cm of the water column. Removal of riparian vegetation, and the shade it provides, contributes to elevated stream temperatures (Rishel et al., 1982; Brown, 1983; Beschta et al., 1987). The principal source of heat energy delivered to the water column is solar energy striking the stream surface directly (Brown 1970). Exposure to direct solar radiation will often cause a dramatic increase in stream temperatures. The ability of riparian vegetation to shade the stream throughout the day depends on land cover height, width, density and position relative to the stream (i.e. stream aspect). *Solar Radiation* (Φ_{Solar}) is a function of the solar angle, solar azimuth, solar declination, atmospheric properties, topography, location and near stream land cover. Simulation is based on methodologies developed by Ibqal (1983), Beschta and Weatherred (1984), Chen (1996) and Boyd (1996).

Both the atmosphere and vegetation along stream banks emit longwave radiation that can heat the stream surface. Water is nearly opaque to longwave radiation and complete absorption of all wavelengths greater than 1.2μ occurs in the first 5 cm (i.e. less than 2 inches) below the surface (Wunderlich, 1972). Longwave radiation has a cooling influence when emitted from the stream surface. The net transfer of heat via longwave radiation usually balances so that the amount of heat entering is similar to the rate of heat leaving the stream (Beschta and Weatherred, 1984; Boyd, 1996). Warm stream temperatures often cause the longwave radiation balance to become negative and the net longwave heat exchange from the atmosphere, near stream land cover and stream surface has a cooling effect (Boyd, 1996). *Longwave Radiation* ($\Phi_{Longwave}$) is derived by the Stefan-Boltzmann Law and is a function of the emissivity of the body, the Stefan-Boltzmann constant and the temperature of the body (Wunderlich, 1972)

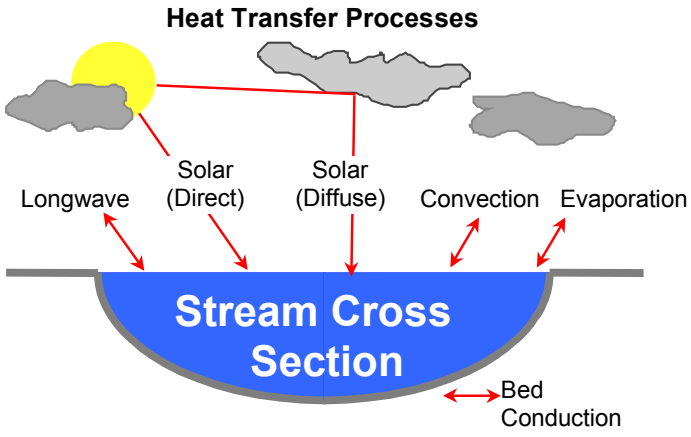
Evaporation occurs in response to internal energy of the stream (molecular motion) that randomly expels water molecules from the stream surface into the overlying air mass. Evaporation is the most effective method of dissipating heat from water (Parker and Krenkel, 1969). As stream temperatures increase, so does the rate of evaporation. Air movement (wind) and low vapor pressures increase the rate of evaporation and accelerate stream cooling (Harbeck and Meyers, 1970). *Evaporation* ($\Phi_{Evaporation}$) relies on a Dalton-type equation that utilizes an exchange coefficient, the latent heat of vaporization, wind speed, saturation vapor pressure and vapor pressure (Wunderlich, 1972).

Convection transfers heat between the stream and the air via molecular and turbulent conduction (Beschta and Weatherred, 1984). Heat is transferred in the direction of warmer to cooler. Air can have a warming influence on the stream when the stream is cooler. The opposite is also true. The amount of convective heat transfer between the stream and air is low (Parker and Krenkel, 1969; Brown, 1983, Beschta and Weatherred, 1984). Nevertheless, air temperatures play a role in stream temperature dynamics via convection, as well as, secondary effects to other heat transfer processes affected by vapor pressure and atmospheric thermal radiation. All of these processes are accounted for in the simulation methodology. *Convection* ($\Phi_{Convection}$) is a function of the Bowen Ratio and terms include atmospheric pressure, and water and air temperatures.

Depending on streambed composition, shallow streams (less than 20 cm) may allow solar radiation to warm the streambed (Brown, 1969). Large cobble (> 25 cm diameter) dominated streambeds in shallow streams may store and conduct heat as long as the bed is warmer than the stream. Bed conduction may cause maximum stream temperatures to occur later in the day, possibly into the evening hours. *Bed Conduction* ($\Phi_{Conduction}$) simulates the theoretical relationship ($\Phi_{Conduction} = K \cdot dT_b / dz$), where calculations are a function of thermal conductivity of the bed (K) and the temperature gradient of the bed (dT_b/dz) (Sinokrot and Stefan, 1993). Bed conduction is solved with empirical equations developed by Beschta and Weatherred (1984).

Net Heat Flux Continuity Equation,

$$\Phi_{Total} = \Phi_{Solar} + \Phi_{Longwave} + \Phi_{Evaporation} + \Phi_{Convection} + \Phi_{Conduction}.$$



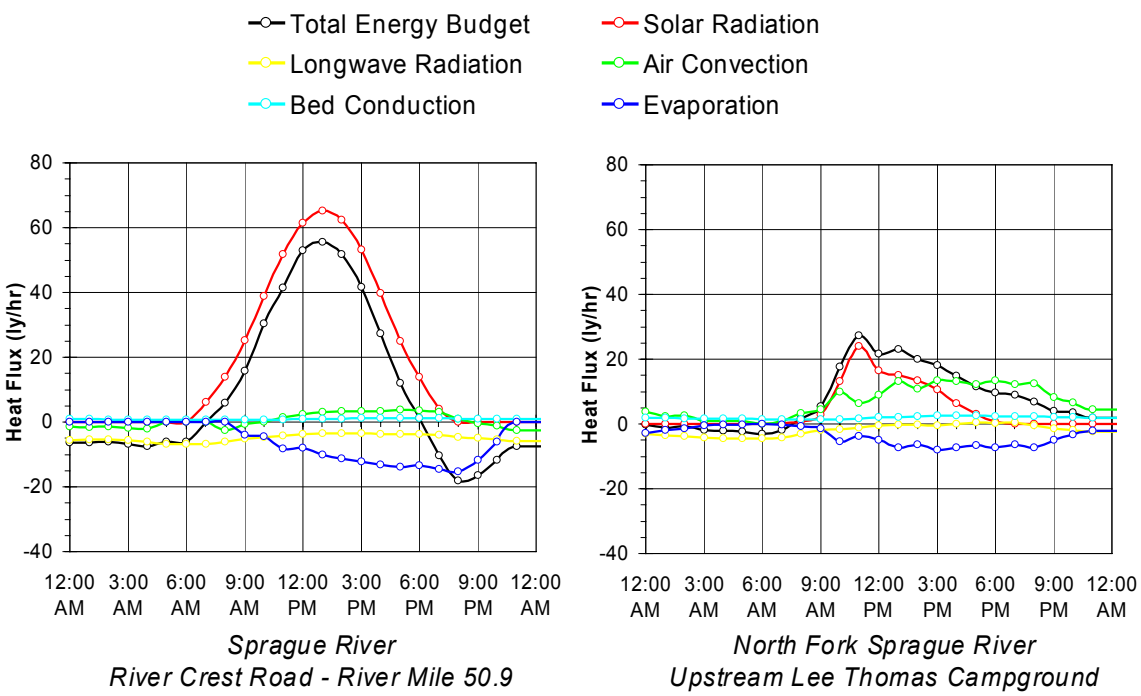


Figure 4-21. *Examples of simulated heat transfer processes. These heat transfer outputs are generated at every distance node in the model methodology.*

The rate change in stream temperature is driven by the heat energy flux (Φ_i). It is easily shown that a defined volume of water will attain a predictable rate change in temperature, provided an accurate prediction of the heat energy flux. The rate change in stream temperature (T) is calculated as a function of wetted channel heat flux, wetted depth and several constants.

Rate Change in Temperature Caused by Heat Energy Thermodynamics,

$$\frac{\partial T}{\partial t} = \left(\frac{Ax_i \cdot \Phi_i}{\rho \cdot c_p \cdot V_i} \right),$$

Which reduces to,

$$\frac{\partial T}{\partial t} = \left(\frac{\Phi_i}{\rho \cdot c_p \cdot D_i} \right).$$

Where,

Ax_i: cross-sectional area (m^2)
C_p: specific heat of water (cal $kg^{-1} \cdot {}^oC^{-1}$)
D_i: average stream depth (m)
t: time (s)
T: Temperature (^oC)
V_i: Volume (m^3)
Φ_i: total heat energy flux (cal $m^{-2} \cdot s^{-1}$)
ρ: density of water (1000 kg/m^3)

4.3.1.2 Mass Transfer Processes

Stream flow velocity (U_x) is calculated using Manning's equation as a function of the channel hydraulic radius (R_h), stream gradient (S_o) and channel roughness estimates (n). The hydraulic radius is the ratio of the cross-sectional area (A_x) to the wetted perimeter (P_w). Channel shape is assumed to be rectangular. Under this assumption, the wetted cross-sectional area is the product of average depth (D) and wetted width (W). The wetted perimeter is the sum of the two wetted channel sides and the wetted width ($2 \cdot D + W$). Stream gradient data is derived from digital elevation model data and stream segment length information from digitized stream polylines (see **Section 3.4.3**). Wetted width data is sampled from digitized channel polylines from aerial photos. Simulation inputs for channel roughness values are within the literature values for Rosgen level I stream types.

$$U_x = \frac{1}{n} \cdot S_o^{1/2} \cdot R_h^{2/3} = \frac{1}{n} \cdot S_o^{1/2} \cdot \left(\frac{A_x}{P_w} \right)^{2/3} = \frac{1}{n} \cdot S_o^{1/2} \cdot \left(\frac{D \cdot W}{2 \cdot D + W} \right)^{2/3}$$

Advection redistributes heat energy in the positive longitudinal direction. No heat energy is lost or gained by the system during advection, and instead, heat energy is transferred downstream as a function of flow velocity. In the case where flow is uniform, the rate change in temperature due to advection is expressed in the first order partial differential equation below.

Rate Change in Temperature Caused by Advection,

$$\frac{\partial T}{\partial t} = -U_x \cdot \frac{\partial T}{\partial x}$$

Dispersion processes occur in both the upstream and downstream direction along the longitudinal axis. Heat energy contained in the system is conserved throughout dispersion, and similar to advection, heat energy is simply moved throughout the system. The rate change in temperature due to dispersion is expressed in the second order partial differential equation below.

Rate Change in Temperature Caused by Dispersion,

$$\frac{\partial T}{\partial t} = D_L \cdot \frac{\partial^2 T}{\partial x^2}$$

The dispersion coefficient (D_L) may be calculated by stream dimensions, roughness and flow. In streams that exhibit high flow velocities and low longitudinal temperature gradients, it may be assumed that the system is advection dominated and the dispersion coefficient may be set to zero (Sinokrot and Stefan 1993). In the event that dispersion effects are considered significant, the appropriate value for the dispersion coefficient can be estimated with a practical approach developed and employed in the QUAL 2e model (Brown and Barnwell 1987). An advantage to this approach is that each parameter is easily measured, or in the case of Manning's coefficient (n) and the dispersion constant (K_d), estimated.

Physical Dispersion Coefficient,

$$D_L = C \cdot K_d \cdot n \cdot U_x \cdot D^{\frac{5}{6}}$$

The simultaneous non-uniform one-dimensional transfer of heat energy is the summation of the rate change in temperature due to heat energy thermodynamics, advection and dispersion. Given that the stream is subject to steady flow conditions and is well mixed, transverse temperature gradients are negligible (Sinokrot and Stefan 1993). An assumption of non-uniform flow implies that cross-sectional area and flow velocity vary with respect to longitudinal position.

The following second ordered parabolic partial differential equation describes the rate change in temperature for non-uniform flow.

Non-Uniform One-dimensional Heat Energy Transfer,

$$\frac{\partial T}{\partial t} = -U_x \cdot \frac{\partial T}{\partial x} + D_L \cdot \frac{\partial^2 T}{\partial x^2} + \frac{\Phi}{c_p \cdot \rho \cdot D}$$

$$\text{Steady Flow: } \frac{\partial U_x}{\partial t} = 0$$

$$\text{Non-Uniform Flow: } \frac{\partial U_x}{\partial x} \neq 0$$

Where,

- A_x: Cross-Sectional area of wetted channel (m^2)
- C: Unit conversion
  - C = 3.82 for English units
  - C = 1.00 for Metric units
- c_p: Specific heat of water (10^3 cal kg^{-1} K^{-1})
- D: Average stream depth (m)
- D_L: Dispersion coefficient (m^2/s)
- Φ: Heat flux (cal m^{-2} s)
- K_d: Dispersion constant
- N: Manning's coefficient
- P_w: Wetted perimeter (m)
- R_h: Hydraulic radius (m)
- ρ: Density of water (10^3 kg m^{-3})
- S_o: Stream gradient
- U_x: Average flow velocity (m/s)
- W: Wetted width (m)

The solution to the *one-dimensional heat energy transfer equation* is essentially the summation of thermodynamic heat energy exchange between the stream system and the surrounding environment and physical processes that redistribute heat energy within the stream system. It is important to note that all heat energy introduced into the stream is conserved, with the net heat energy value reflected as stream temperature magnitude. Further, heat energy is transient within the stream system, due to longitudinal transfer of heat energy (i.e., advection and dispersion). The net heat energy flux (Φ) is calculated at every distance step and time step based on physical and empirical formulations developed for each significant energy component. The dispersion coefficient (D_L) is assumed to equal zero.

4.3.1.3 Boundary Conditions and Initial Values

The temperatures at the upstream boundary (i_o) for all time steps (t_o ,t_1,..., t_{M-1}, t_M) are supplied by the upstream temperature inputs. At the downstream boundary temperature at longitudinal position i_{n+1} is assumed to equals that of i_n with respect to time t. Initial values of the temperatures at each distance node (i_o ,i_1,..., i_{N-1}, i_N) occurring at the starting time (t_o) can be input by the model user or assumed to equal the boundary condition at time t_o.

4.3.1.4 Simulated Scenarios

Once stream temperature models are calibrated, several scenarios are simulated by changing one or more stream input parameters. The simulated scenarios focus largely on defined potential conditions for channel width, land cover and derived mass balances. Combinations of these potential conditions are also simulated to investigate the cumulative thermal effect of attaining defined conditions. These scenarios are also used for sensitivity analysis.

Scenario 1: Current Condition

Scenario 2: Potential Channel Width
All other inputs remain unchanged

Scenario 3: Potential Flow
All other inputs remain unchanged

Scenario 4: Tributaries and Return Flow Temperatures Less than 64^{o}F
All other inputs remain unchanged

Scenario 5: Potential Near Stream Land Cover - High Range
All other inputs remain unchanged

Scenario 6: Potential Near Stream Land Cover - Low Range
All other inputs remain unchanged

Scenario 7: Potential Channel Width
Potential Near Stream Land Cover - High Range
All other inputs remain unchanged

Scenario 8: Potential Channel Width
Potential Near Stream Land Cover - Low Range
All other inputs remain unchanged

Scenario 9: Potential Flow
Potential Channel Width
Potential Near Stream Land Cover - High Range
All other inputs remain unchanged

Scenario 10: Potential Flow
Potential Channel Width
Potential Near Stream Land Cover - Low Range
All other inputs remain unchanged

Scenario 11: Tributaries and Return Flow Temperatures Less than 64^{o}F
Potential Flow
Potential Channel Width
Potential Near Stream Land Cover - High Range
All other inputs remain unchanged

Scenario 12: Tributaries and Return Flow Temperatures Less than 64^{o}F
Potential Flow
Potential Channel Width
Potential Near Stream Land Cover - Low Range
All other inputs remain unchanged

Scenario 13: Tributaries and Return Flow Temperatures Less than 64^{o}F
Potential Channel Width
Potential Near Stream Land Cover - High Range
All other inputs remain unchanged

Scenario 14: Tributaries and Return Flow Temperatures Less than 64^{o}F
Potential Channel Width
Potential Near Stream Land Cover - Low Range
All other inputs remain unchanged

4.3.1.5 Spatial and Temporal Scale

The lengths of the defined finite difference and data input sampling rate is 100 feet. The temperature model is calibrated to analyze and predict stream temperature for one day, however

multiple days can be simulated. Prediction time steps are limited by stability considerations for the finite difference solution method. Periods of simulation occurred in early to mid August. Simulations were performed for a total of 250.6 WRD river miles in the Sprague River and Williamson River subbasin (actual simulation length is 266.0 river miles at 1:5,000 stream polyline scale). **Table 4-3** lists the spatial extent and simulation period for by river system.

Table 4-3. Stream Temperature Simulation Periods and Extent

River/Stream	Simulation Period	Simulation Extent
Williamson River[25]	August 4th	RM 0.0 to 41.5, 56.4 to 82.5
North Fork Sprague River	August 16th	RM 0.0 to 32.4
South Fork Sprague River	August 12th	RM 0.0 to 30.0
Sycan River	August 16th	RM 0.0 to 36.0
Sprague River	August 12th	RM 0.0 to 84.6
		Total Simulation Extent 250.6 WRD river miles[26]

4.3.1.6 Validation - Simulation Accuracy

For the purposes of this analytical effort, validation refers to the statistical comparison of measured and simulated data. Absolute average deviation and standard error statistics are calculated for FLIR derived spatial temperature data sets, instream measured temporal temperature data sets and combined spatial and temporal data sets. Each measurement of temperature is discrete and is used to assess model accuracy. Simulation outputs are only accurate to levels that exceed the validation statistics. A statistically significant simulated result is one that produces a temperature change greater than validation statistics listed in **Table 4-4**.

Stream temperatures derived from FLIR data offer an extremely robust validation data set for spatial stream temperature simulation tools (Faux et al. 2001). Since the FLIR temperature data is continuous, the number of simulated temperatures available for model validation is limited to model resolution. With FLIR temperature data, the spatial scalability for any given methodology is unlimited by validation data. This represents a significant improvement over previous data sources. As an example, ODEQ simulated stream temperatures for the North Fork Sprague River along 57.6 km (35.7 river miles of simulation length). The selected model spatial resolution was 100 meters, allowing 576 discrete model output samples for calculation of validation statistics. A similar effort that relied simply on available instream continuous monitors would have allowed only 96 validation samples. Validation robustness of the simulation is increased by a factor of six when FLIR temperature data are used in the model methodology.

Spatial and temporal data is stratified in the validation to test for biases in the simulation methodology. Since FLIR temperature data sets are robust spatially, there is a possibility that the simulation could be calibrated to the specific time when FLIR data was obtained, yet perform poorly for other periods of the day. However, validation statistics demonstrate that this is not the case. The overall simulation performance is validated using 4,735 discrete measurements and simulations of stream temperatures during the simulation period. The absolute average deviation from measured data is 1.0°F and the standard error in 1.2°F. **Figure 4-22** displays the validation results for each simulated stream and river in the Williamson River and Sprague River subbasins.

[25] Stream temperature was not sampled in Klamath Marsh (river miles 41.5 to 56.4).

[26] Actual stream simulation length is 266 miles. Stream miles have been presented in WRD River Miles for reader DEQ analysis is performed at a higher resolution that captures sinuosity resulting in more stream mileage than WRD maps.

Table 4-4. Stream Temperature Simulation Validation

	Validation Statistic	Williamson River	North Fork Sprague River	South Fork Sprague River	Sycan River	Sprague River	**Total**
Temporal Instream Data	Samples (n)	192	96	48	96	144	576
	Ave. Deviation	2.1	1.6	2.1	2.0	1.4	1.8
	Standard Error	1.3	1.3	0.6	1.3	0.7	0.7
Spatial FLIR Derived Temperature	Samples (n)	1,220	576	506	617	1,240	4,159
	Ave. Deviation	1.2	0.9	0.9	1.0	0.7	0.9
	Standard Error	1.6	1.1	0.8	1.2	1.1	1.2
Total	Samples (n)	1,412	672	554	713	1,384	4,735
	Ave. Deviation	1.3	1.0	1.0	1.1	0.7	1.0
	Standard Error	1.6	1.1	0.8	1.2	1.1	1.2

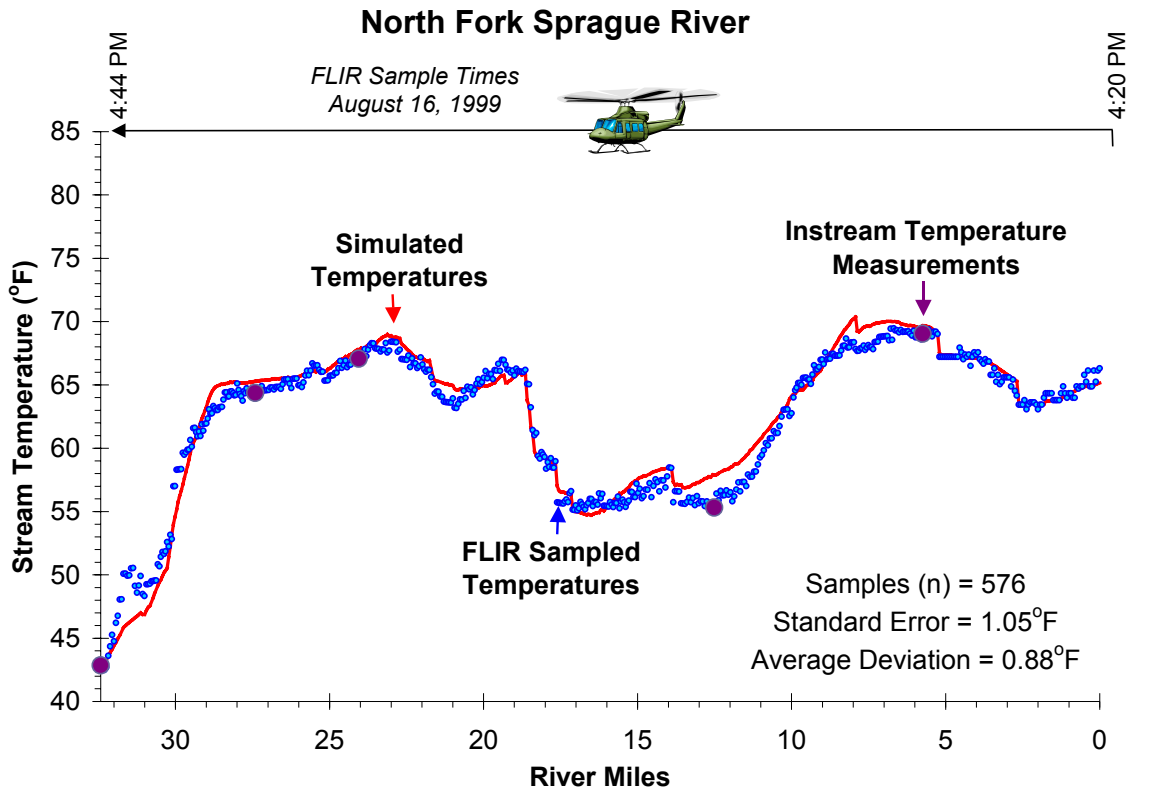


***Figure 4-22**. Stream Temperature Simulation Compared to FLIR Derived Stream Temperatures*

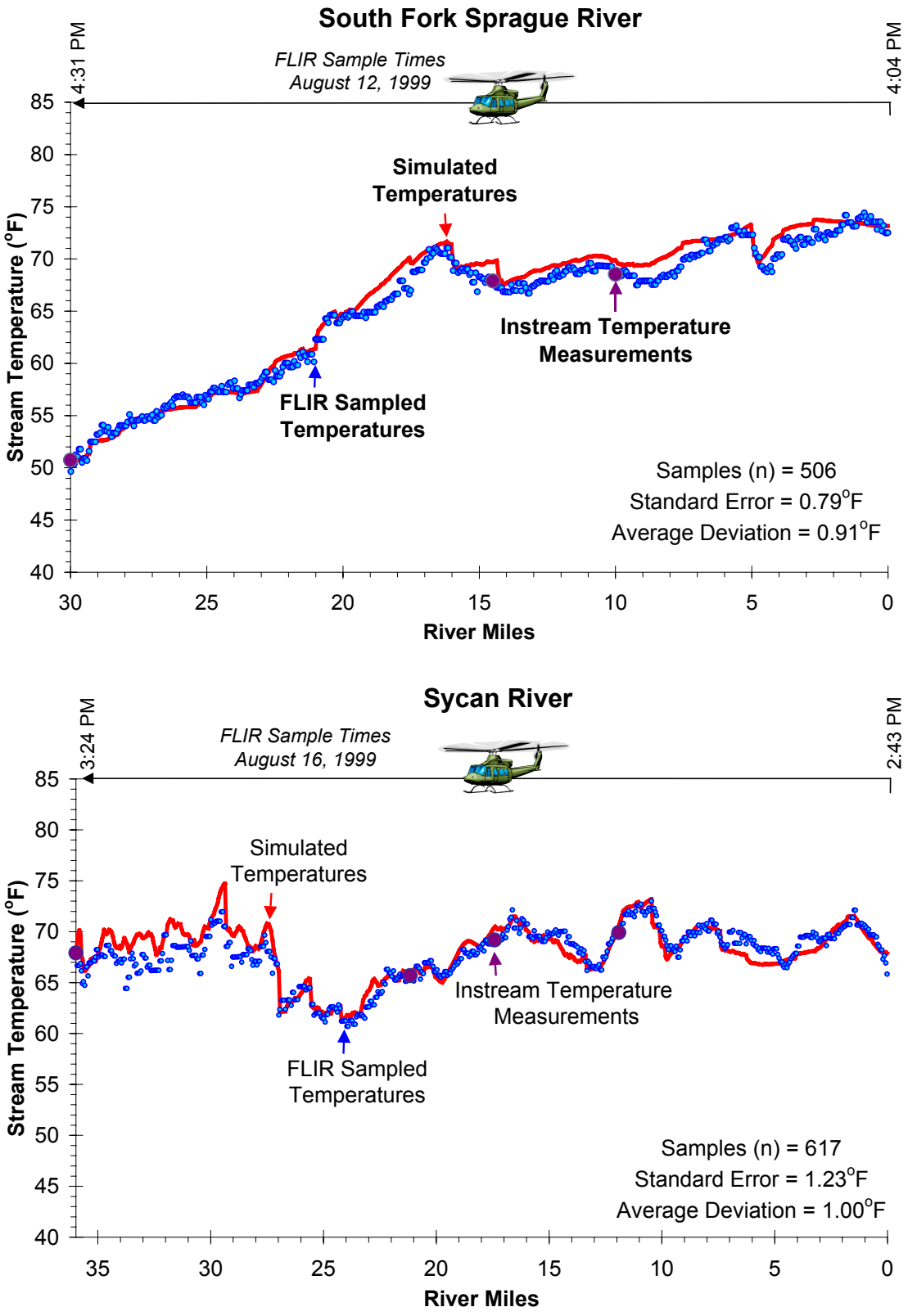


Figure 4-22 (continued). *Stream Temperature Simulation Compared to FLIR Derived Stream Temperatures*

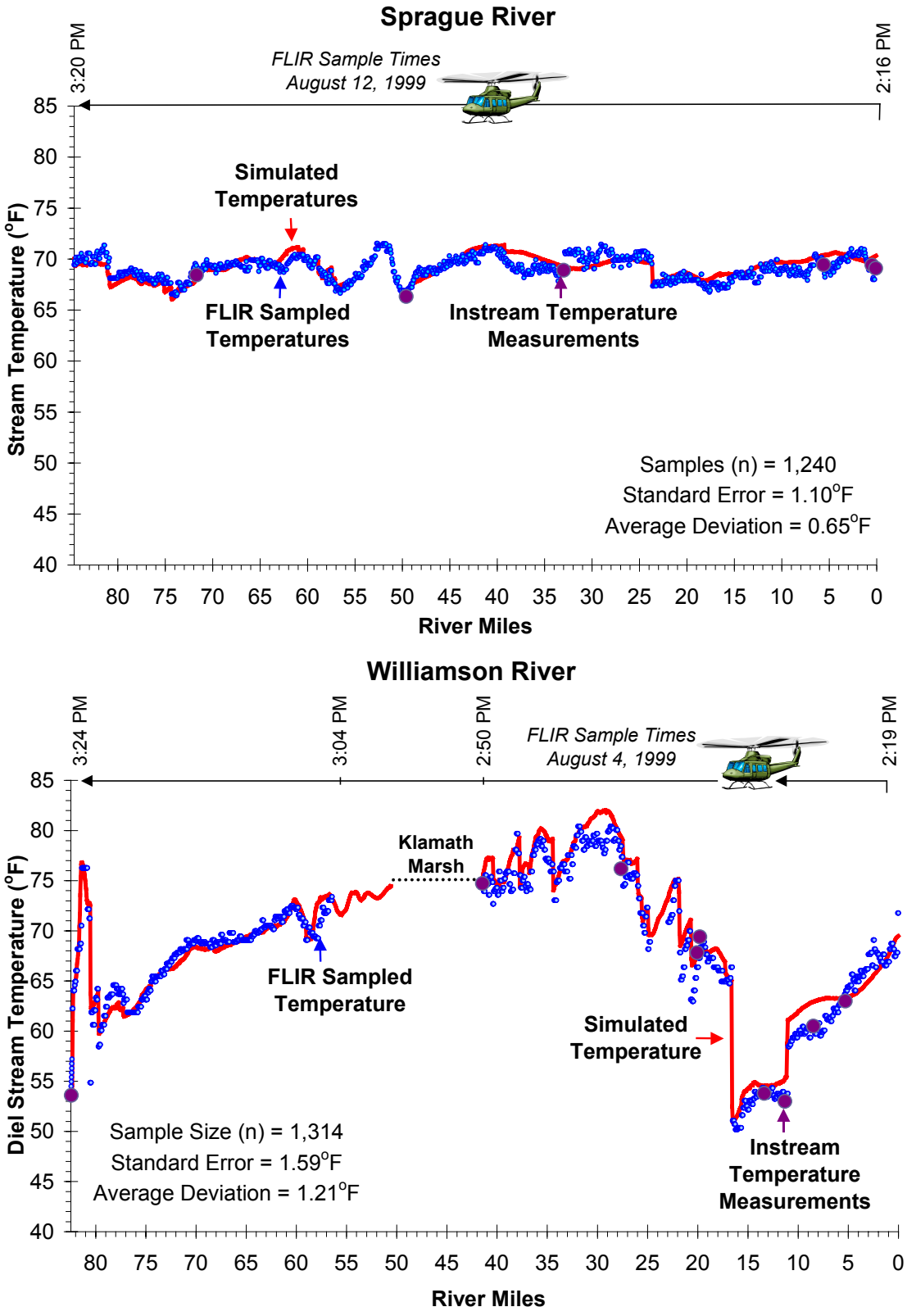


Figure 4-22 (continued). *Stream Temperature Simulation Compared to FLIR Derived Stream Temperatures*

4.3.2 Stream Temperature Simulation Scenarios

4.3.2.1 North Fork Sprague River Stream Temperature Simulations

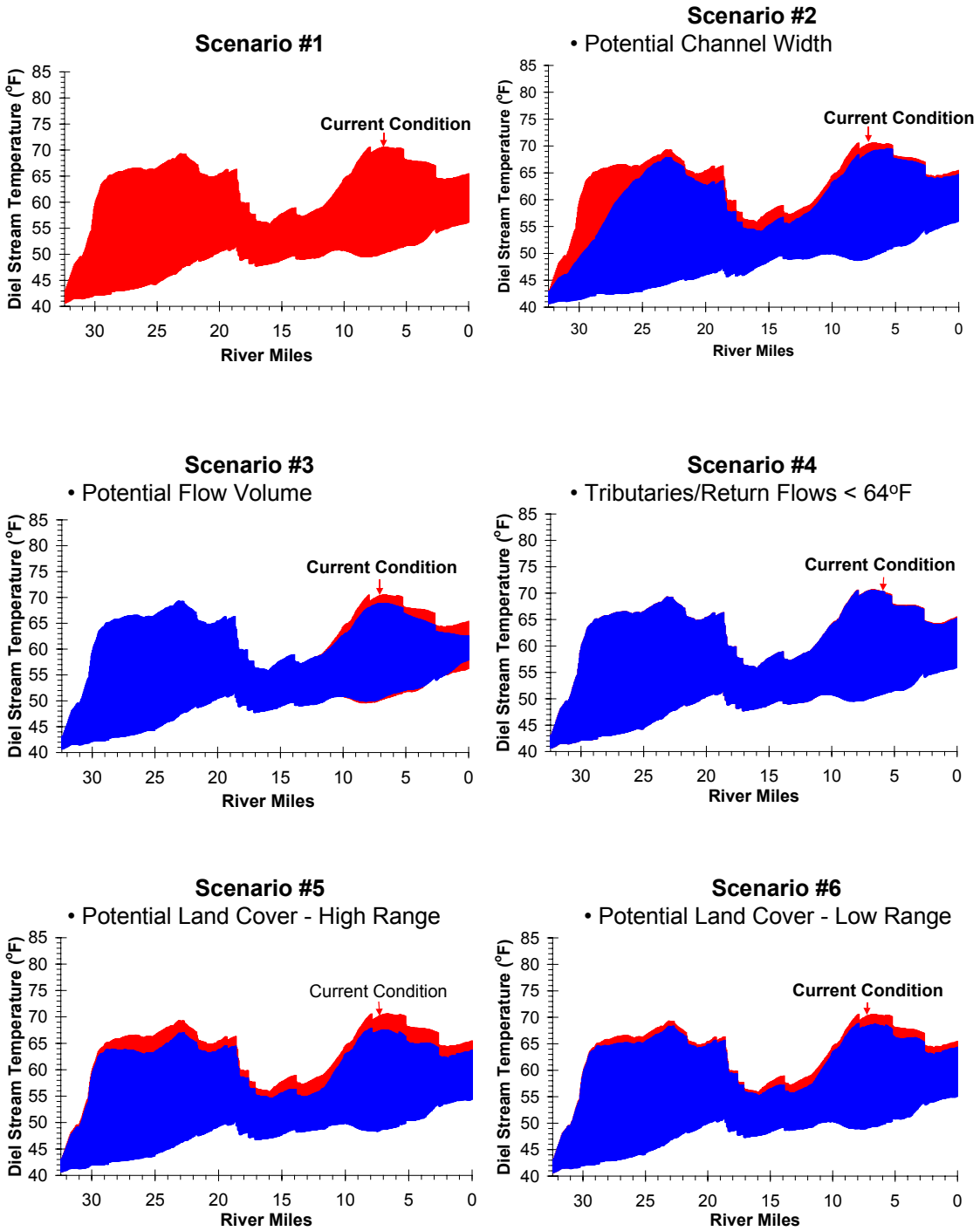


***Figure 4-23**. North Fork Sprague River Simulated Stream Temperature Scenarios*

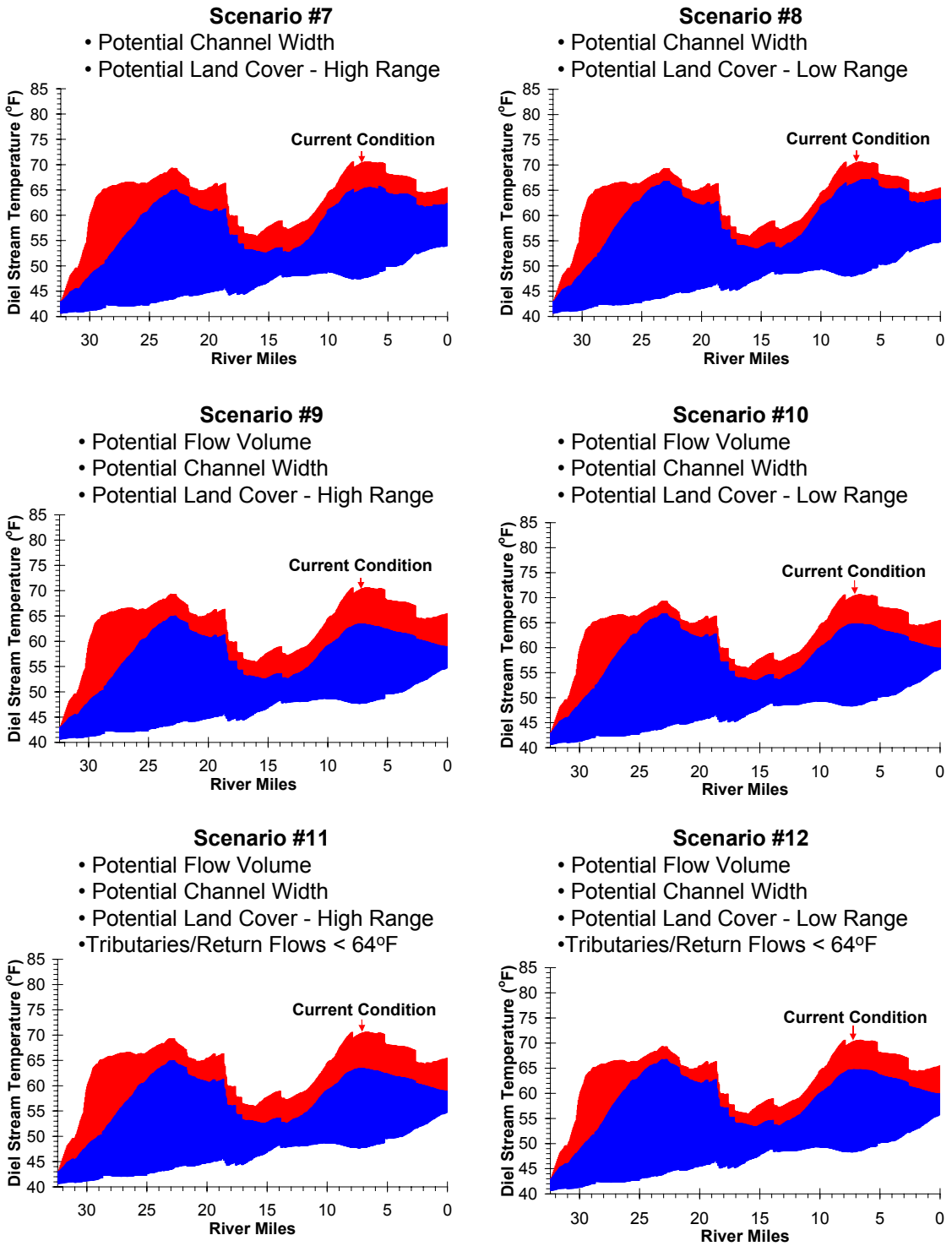


Figure 4-23 (continued). *North Fork Sprague River Simulated Stream Temperature Scenarios*

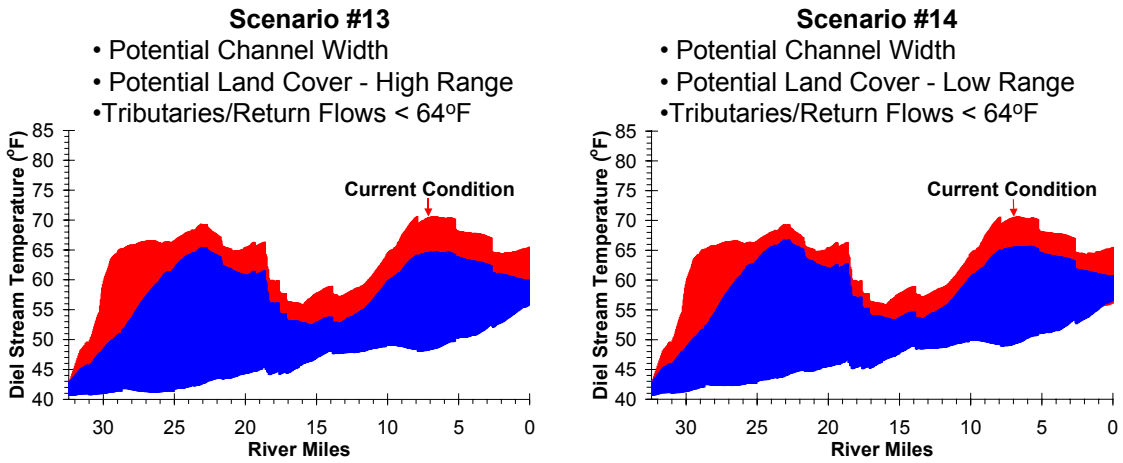


***Figure 4-23 (continued)**. North Fork Sprague River Simulated Stream Temperature Scenarios*

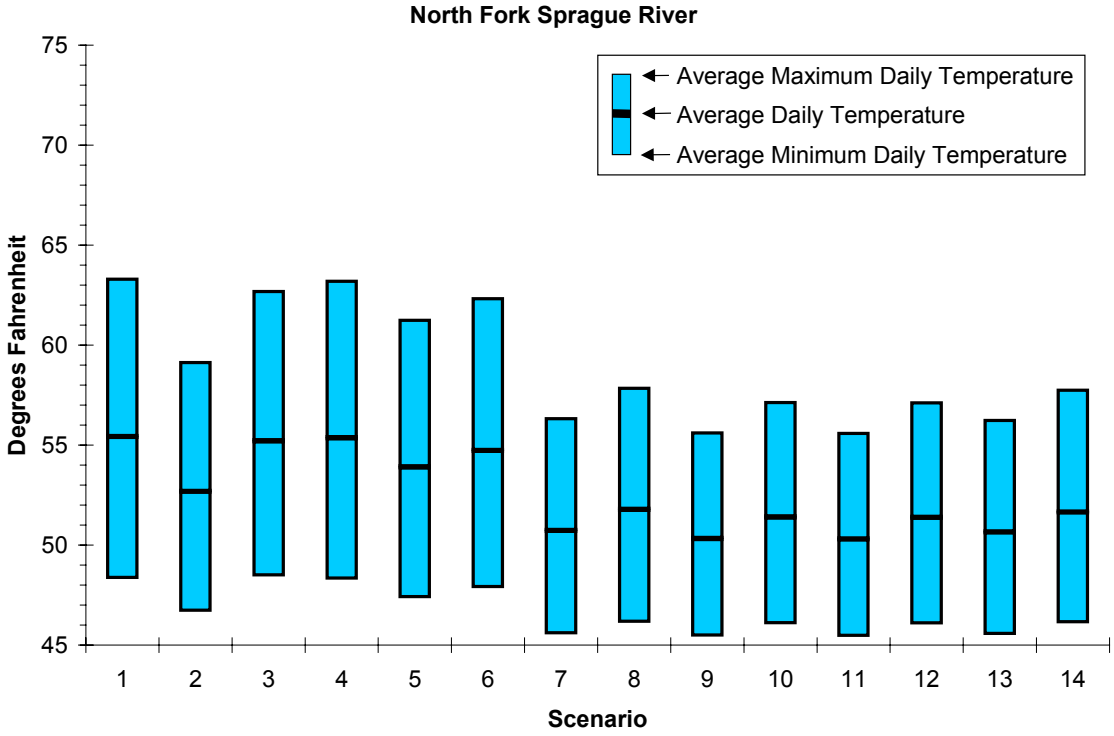


***Figure 4-24**. North Fork Sprague River summary of average maximum stream temperatures for each scenario over the entire simulation length (34.2 river miles).*

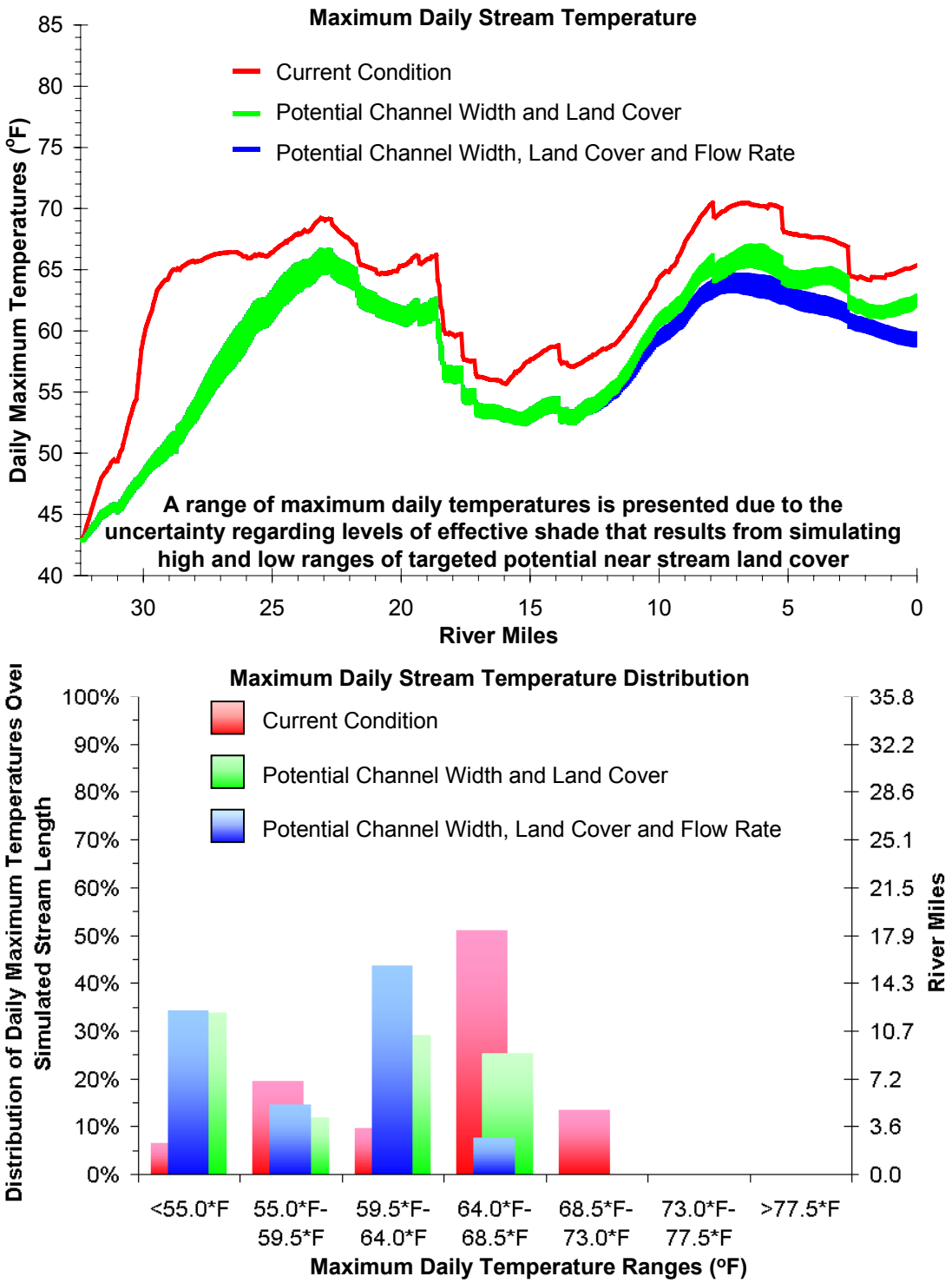


Figure 4-25. *North Fork Sprague River summary of maximum daily simulated potential stream temperatures. Upper chart displays the longitudinal profile of maximum daily stream temperatures. A range is provided showing the range of potential temperatures due to uncertainty related to the potential land cover condition. The lower chart is a histogram that shows the distribution of simulated maximum daily stream temperatures for the current condition compared to potential channel width, land cover and flow rate.*

4.3.2.2 South Fork Sprague River Stream Temperature Simulations

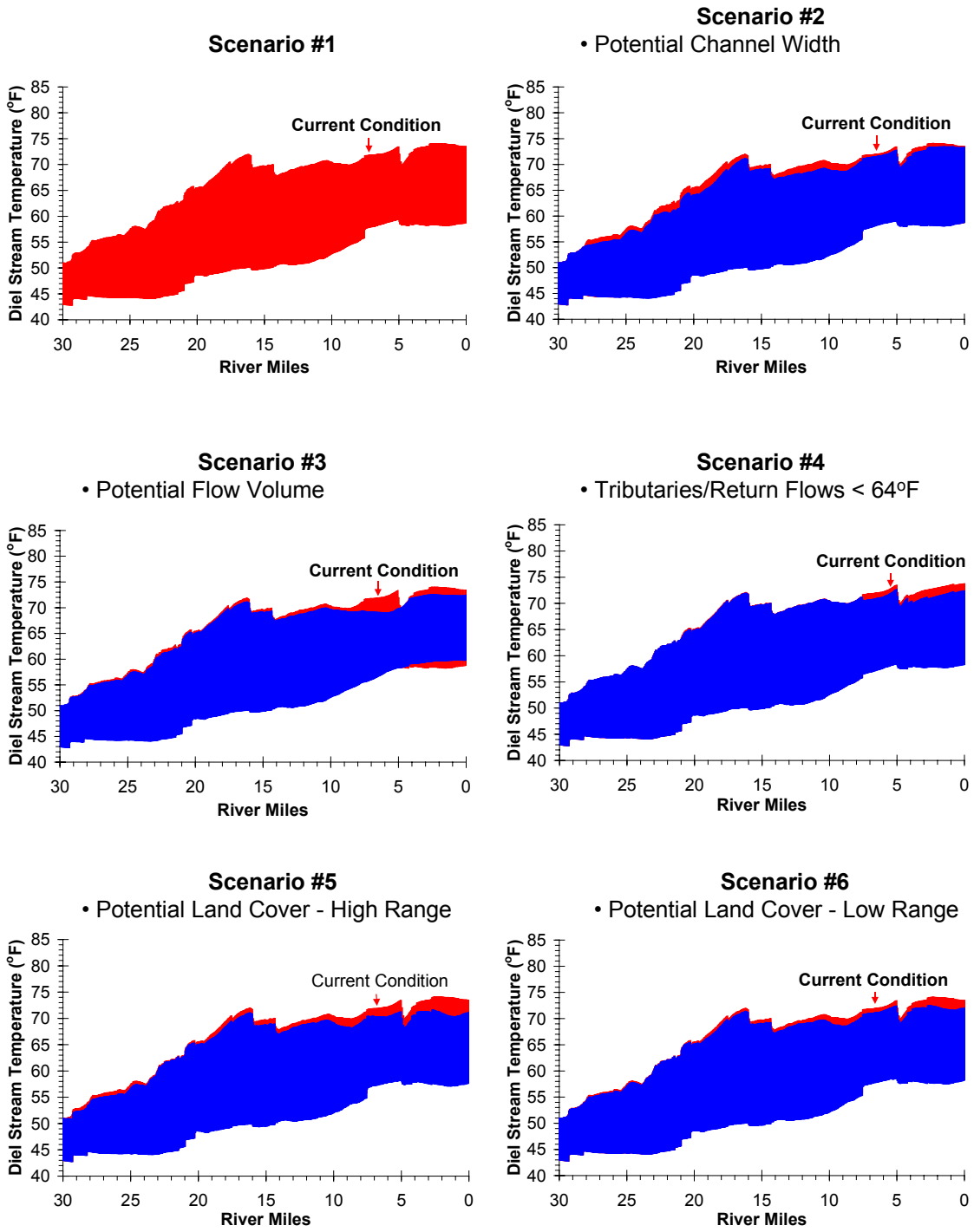


Figure 4-26. *South Fork Sprague River Simulated Stream Temperature Scenarios*

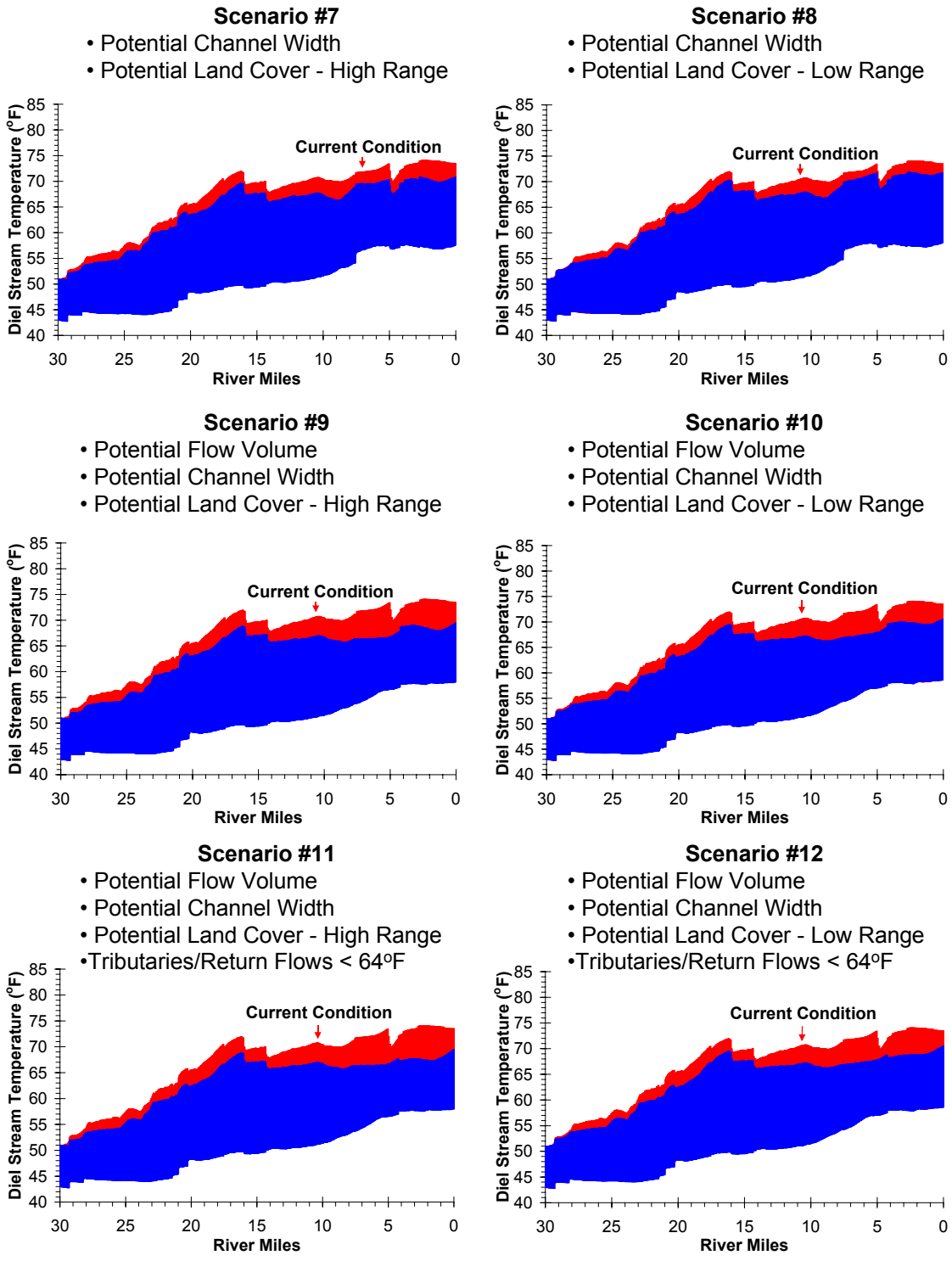


***Figure 4-26 (continued)**. South Fork Sprague River Simulated Stream Temperature Scenarios*

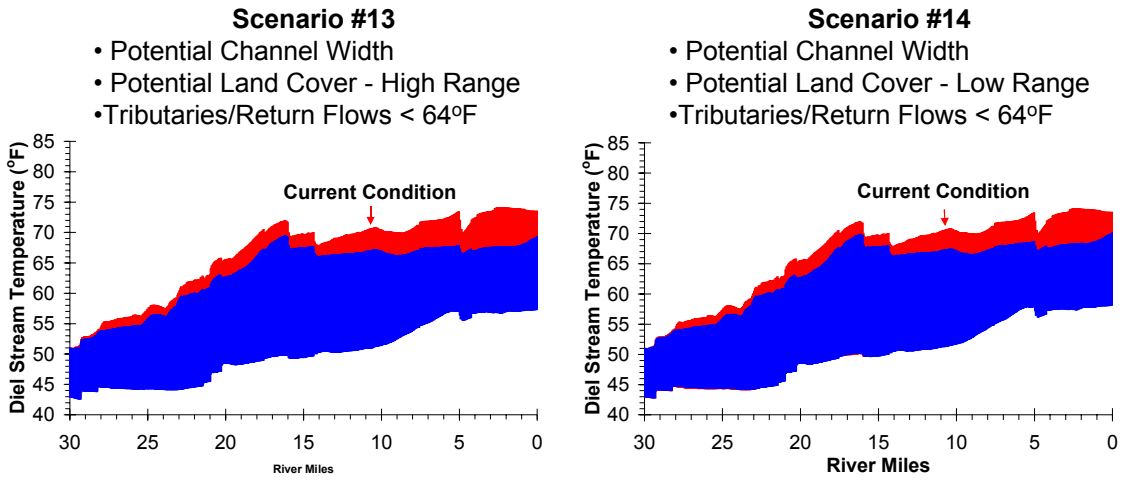


***Figure 4-26 (continued)**. South Fork Sprague River Simulated Stream Temperature Scenarios*

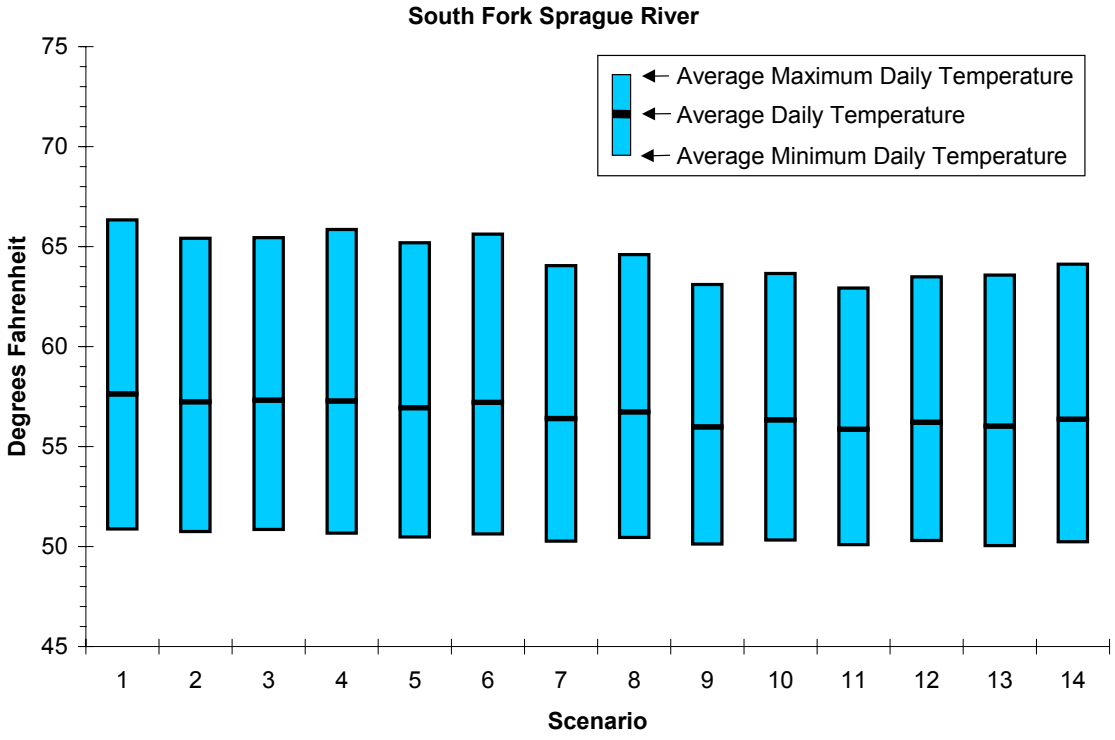


***Figure 4-27**. South Fork Sprague River Summary Average Simulated Stream Temperature Scenarios. Average values calculated for the entire simulation length (30.0 river miles).*

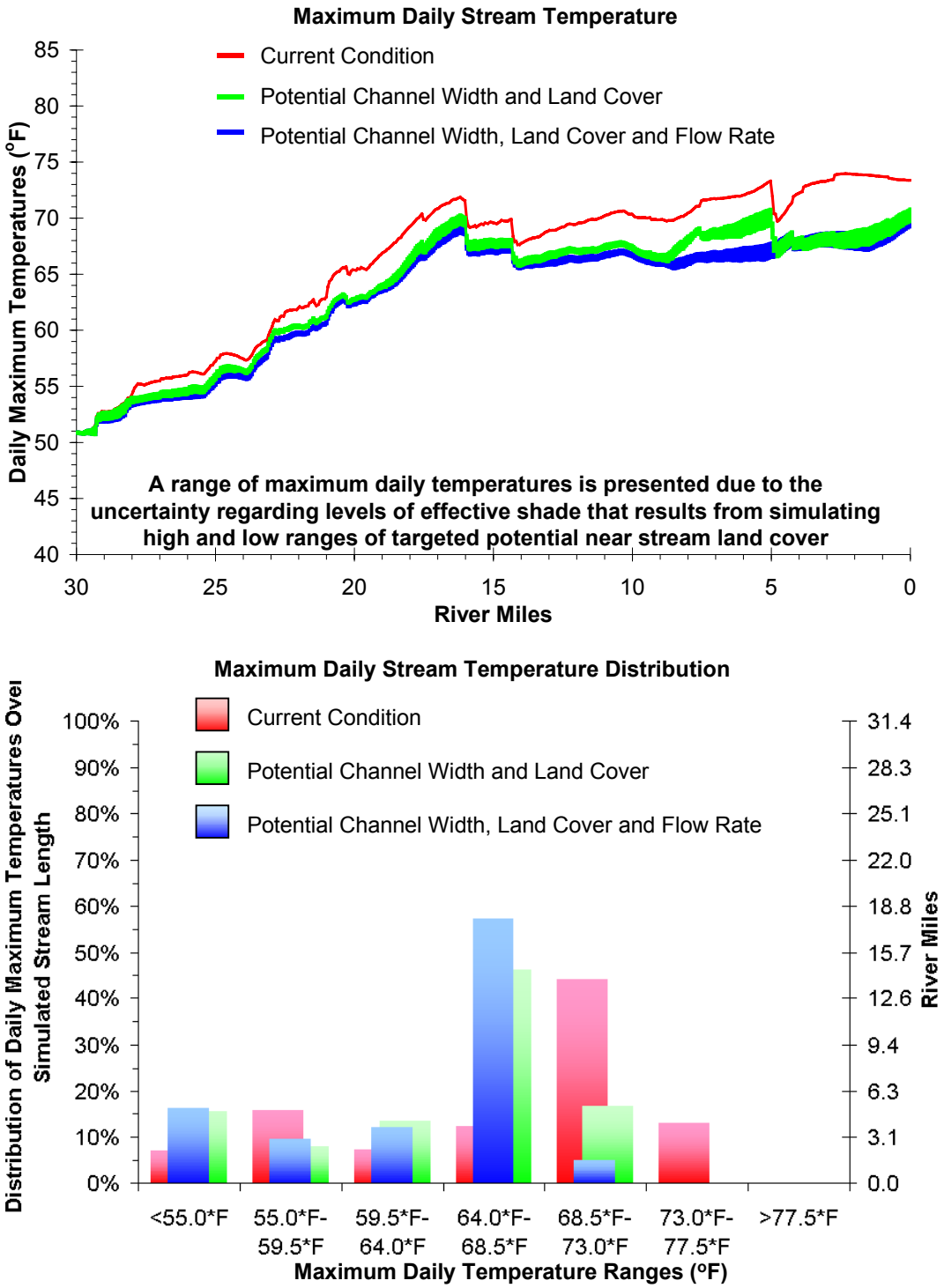


***Figure 4-28**. South Fork Sprague River summary of maximum daily simulated potential stream temperatures. Upper chart displays the longitudinal profile of maximum daily stream temperatures. A range is provided showing the range of potential temperatures due to uncertainty related to the potential land cover condition. The lower chart is a histogram that shows the distribution of simulated maximum daily stream temperatures for the current condition compared to potential channel width, land cover and flow rate.*

4.3.2.3 Sycan River Stream Temperature Simulations

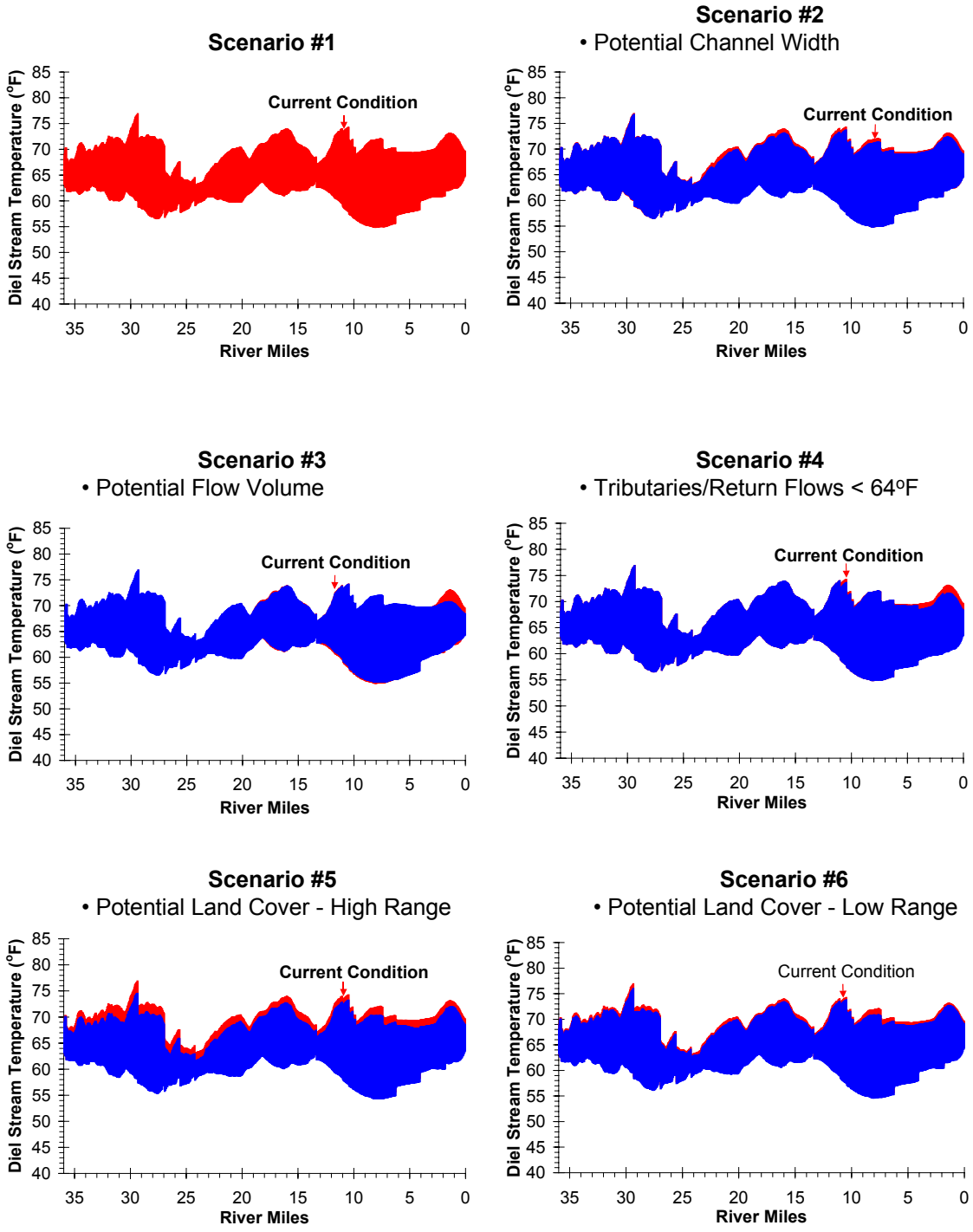


Figure 4-29. *Sycan River Simulated Stream Temperature Scenarios*

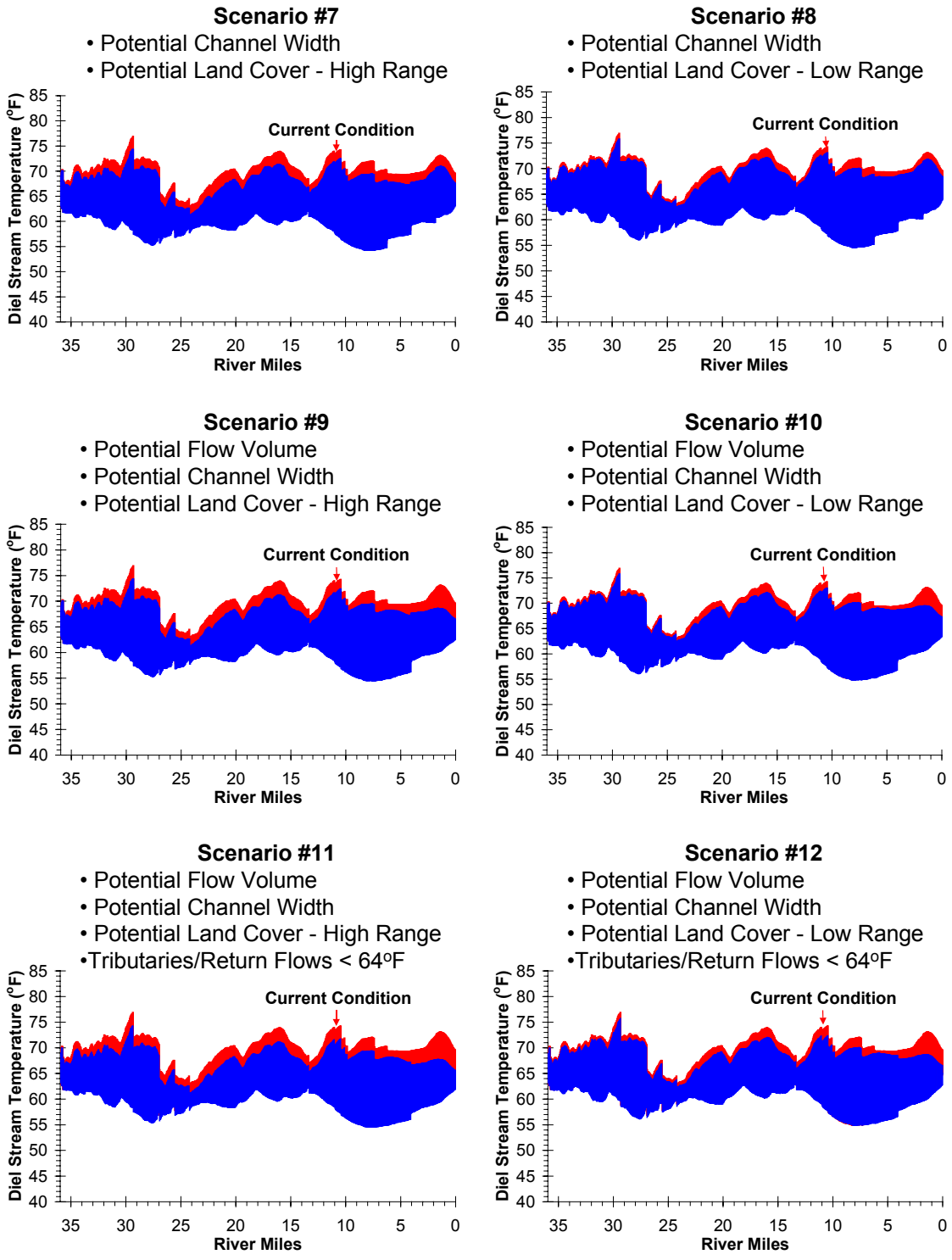


***Figure 4-29 (continued)**. Sycan River Simulated Stream Temperature Scenarios*

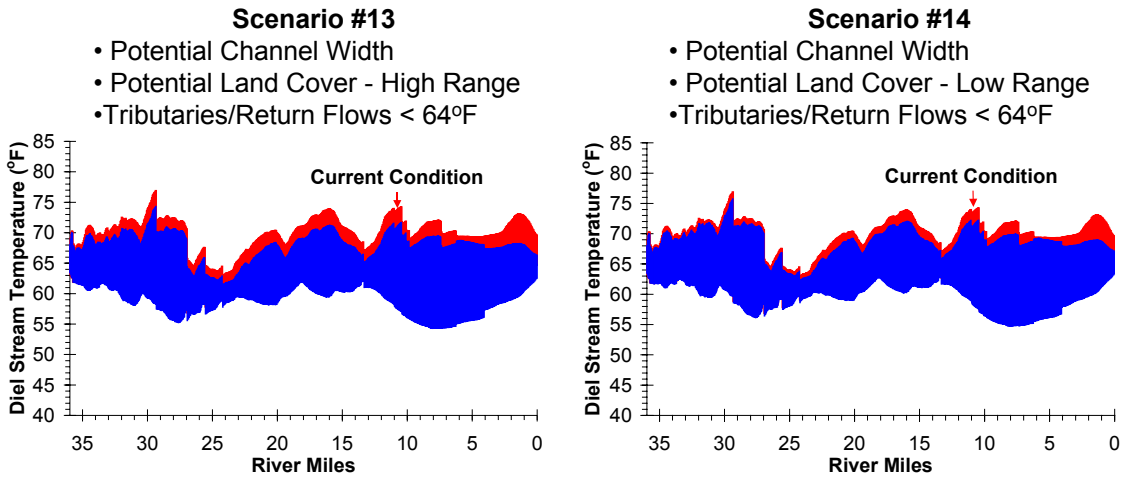


***Figure 4-29 (continued)**. Sycan River Simulated Stream Temperature Scenarios*

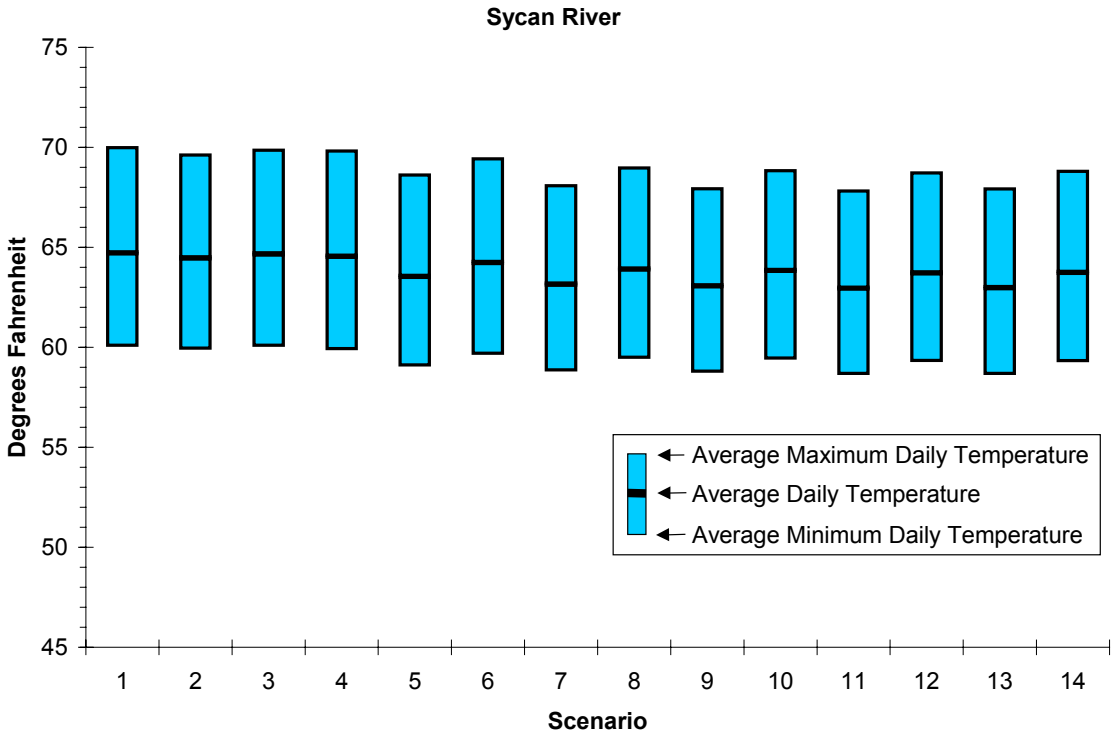


***Figure 4-30**. Sycan River Summary Average Simulated Stream Temperature Scenarios. Average values calculated for the entire simulation length (36.0 river miles).*

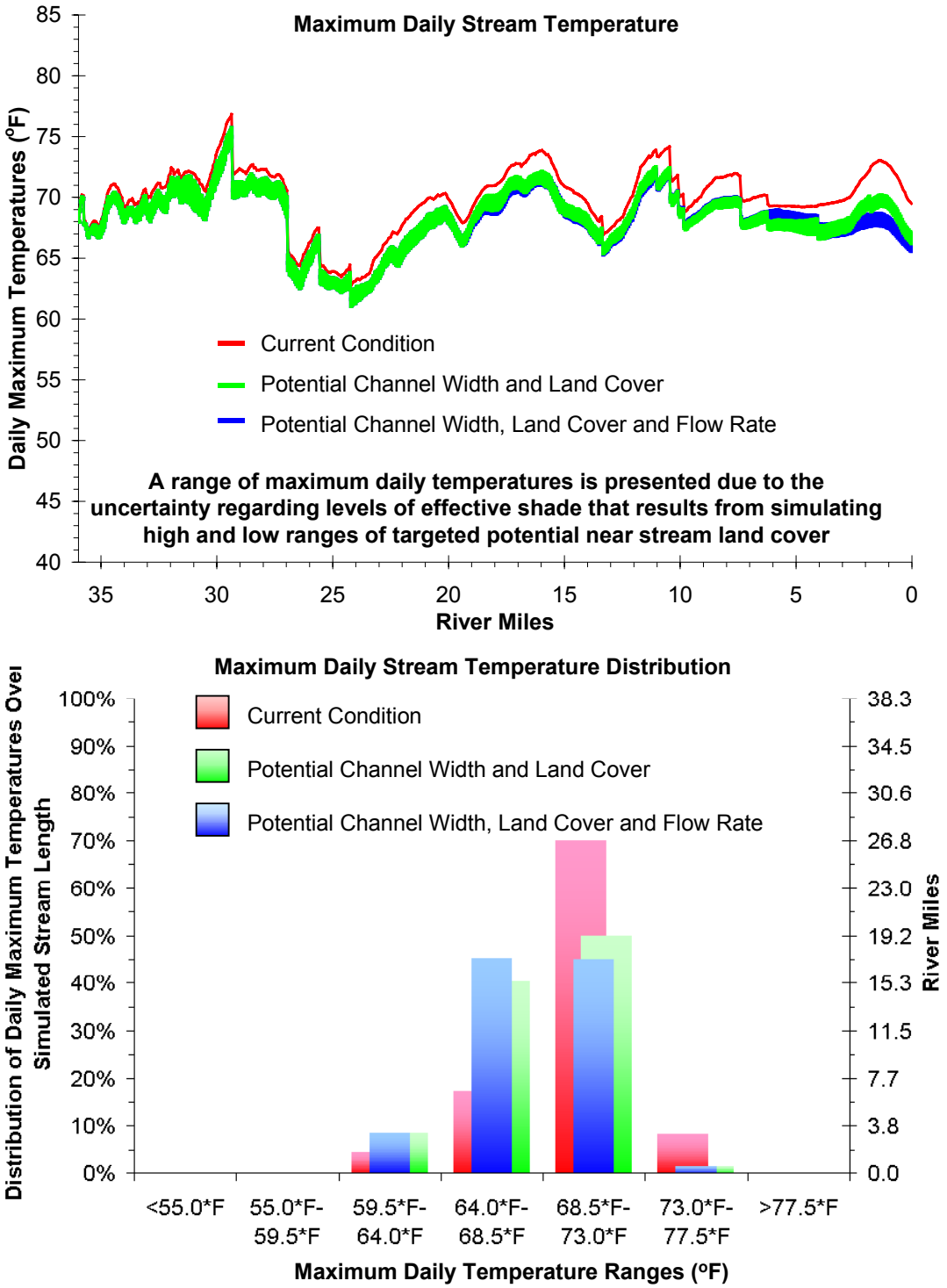


***Figure 4-31**. Sycan River summary of maximum daily simulated potential stream temperatures. Upper chart displays the longitudinal profile of maximum daily stream temperatures. A range is provided showing the range of potential temperatures due to uncertainty related to the potential land cover condition. The lower chart is a histogram that shows the distribution of simulated maximum daily stream temperatures for the current condition compared to potential channel width, land cover and flow rate.*

4.3.2.4 Sprague River Stream Temperature Simulations

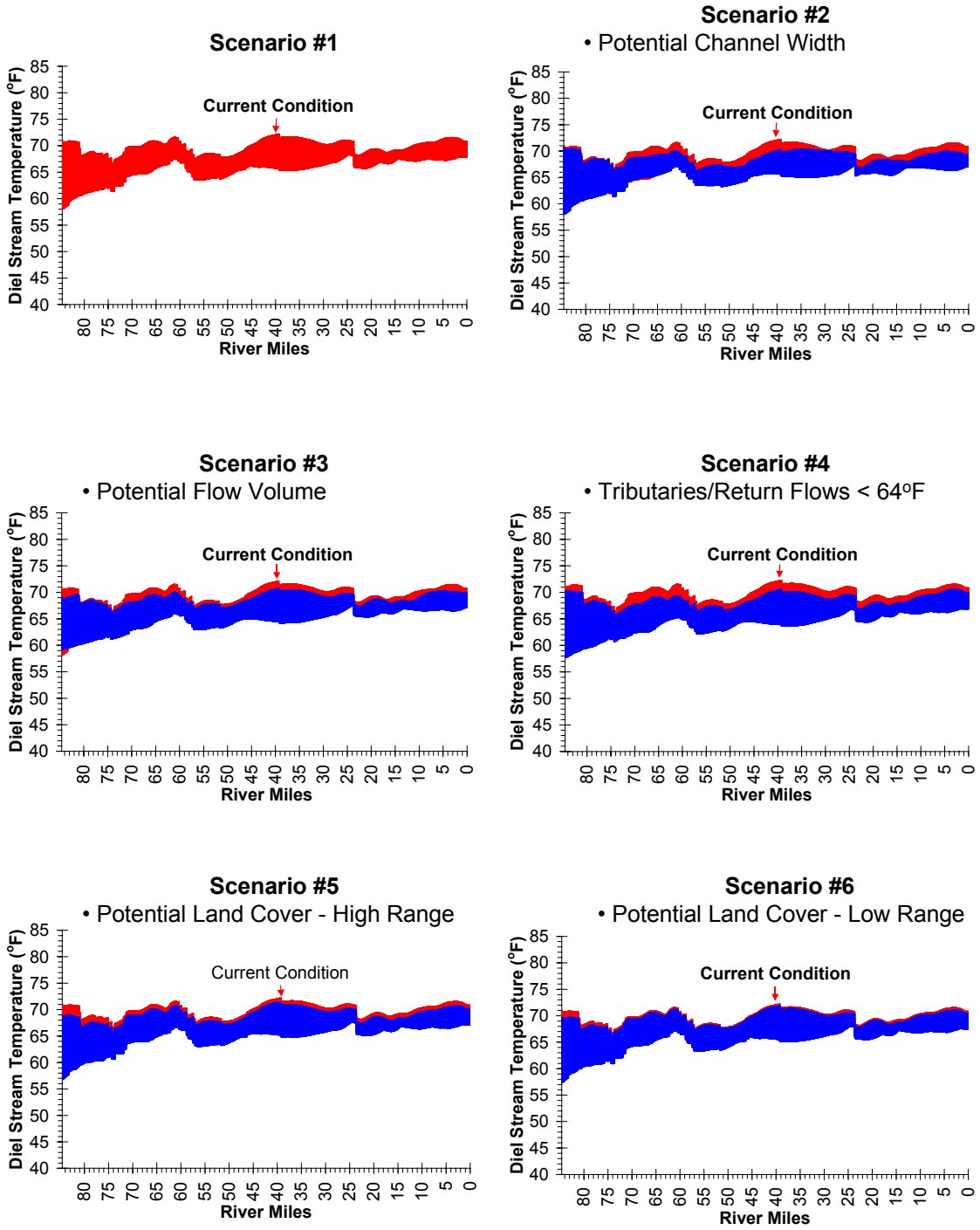


Figure 4-32. *Sprague River Simulated Stream Temperature Scenarios*

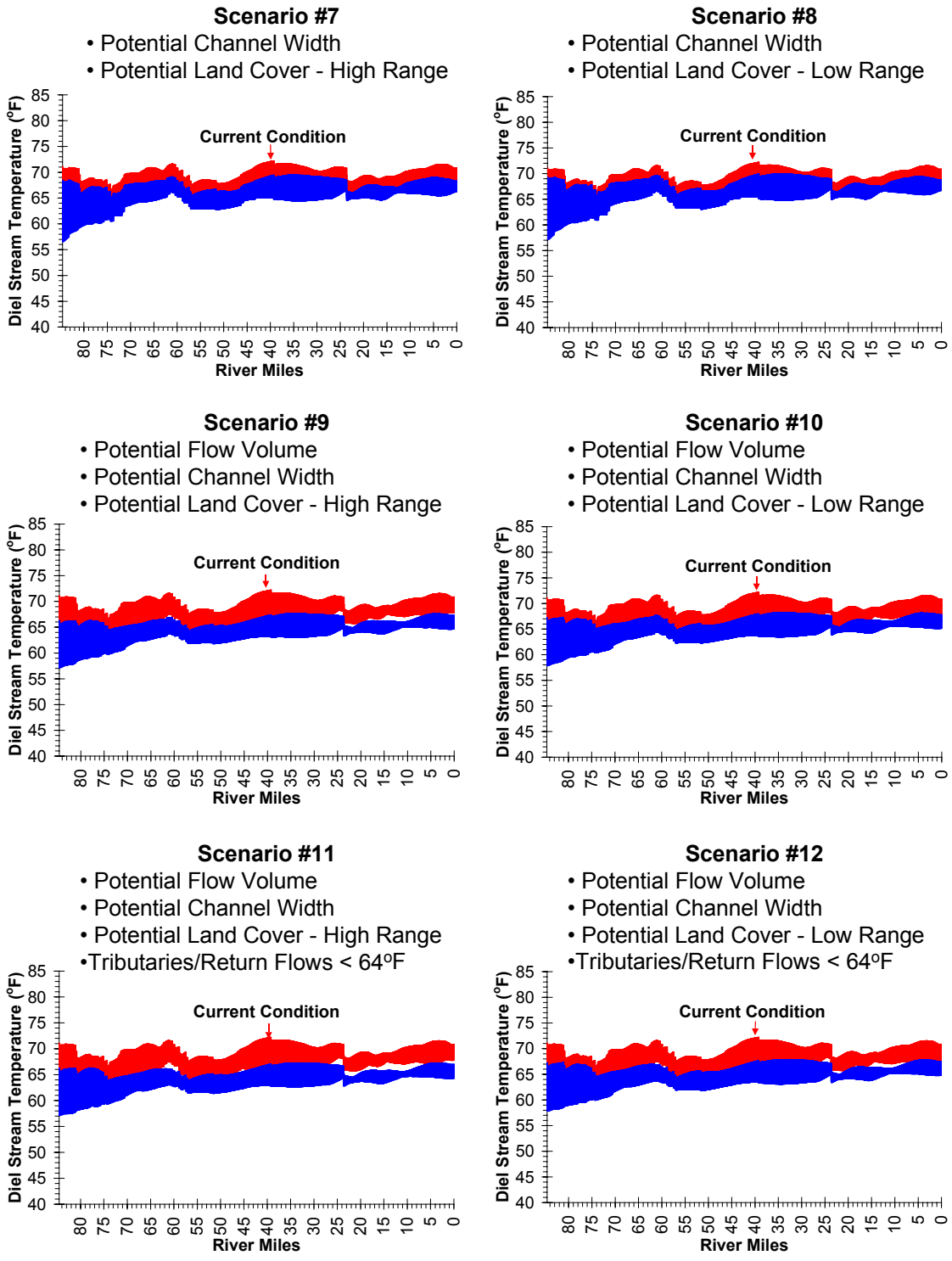


***Figure 4-32 (continued)**. Sprague River Simulated Stream Temperature Scenarios*

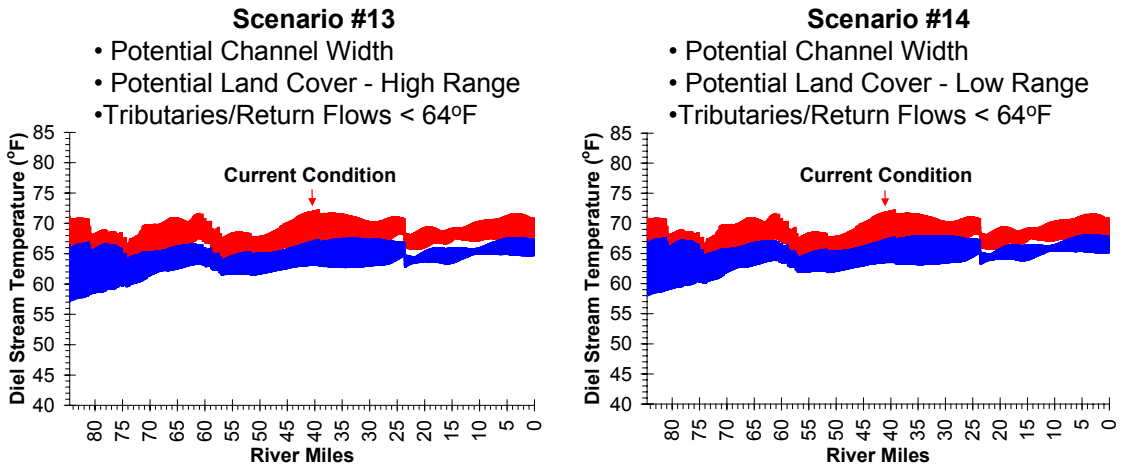


***Figure 4-32 (continued)**. Sprague River Simulated Stream Temperature Scenarios*

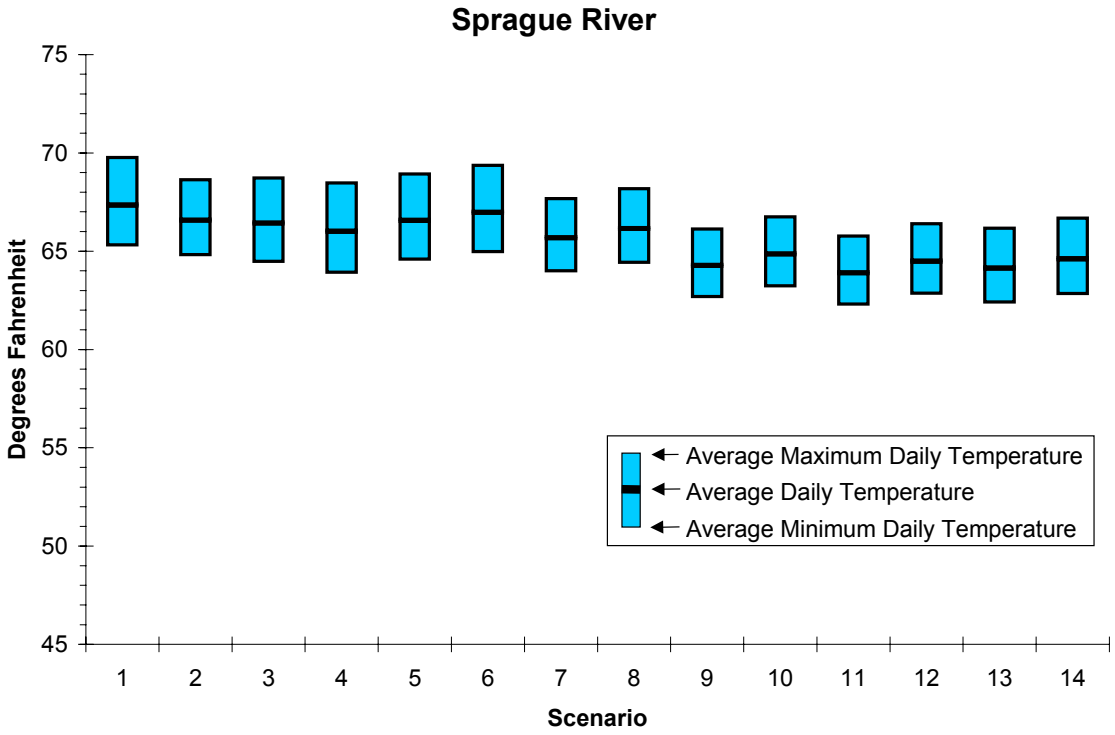


***Figure 4-33**. Sprague Summary Average Simulated Stream Temperature Scenarios. Average values calculated for the entire simulation length (84.6 river miles).*

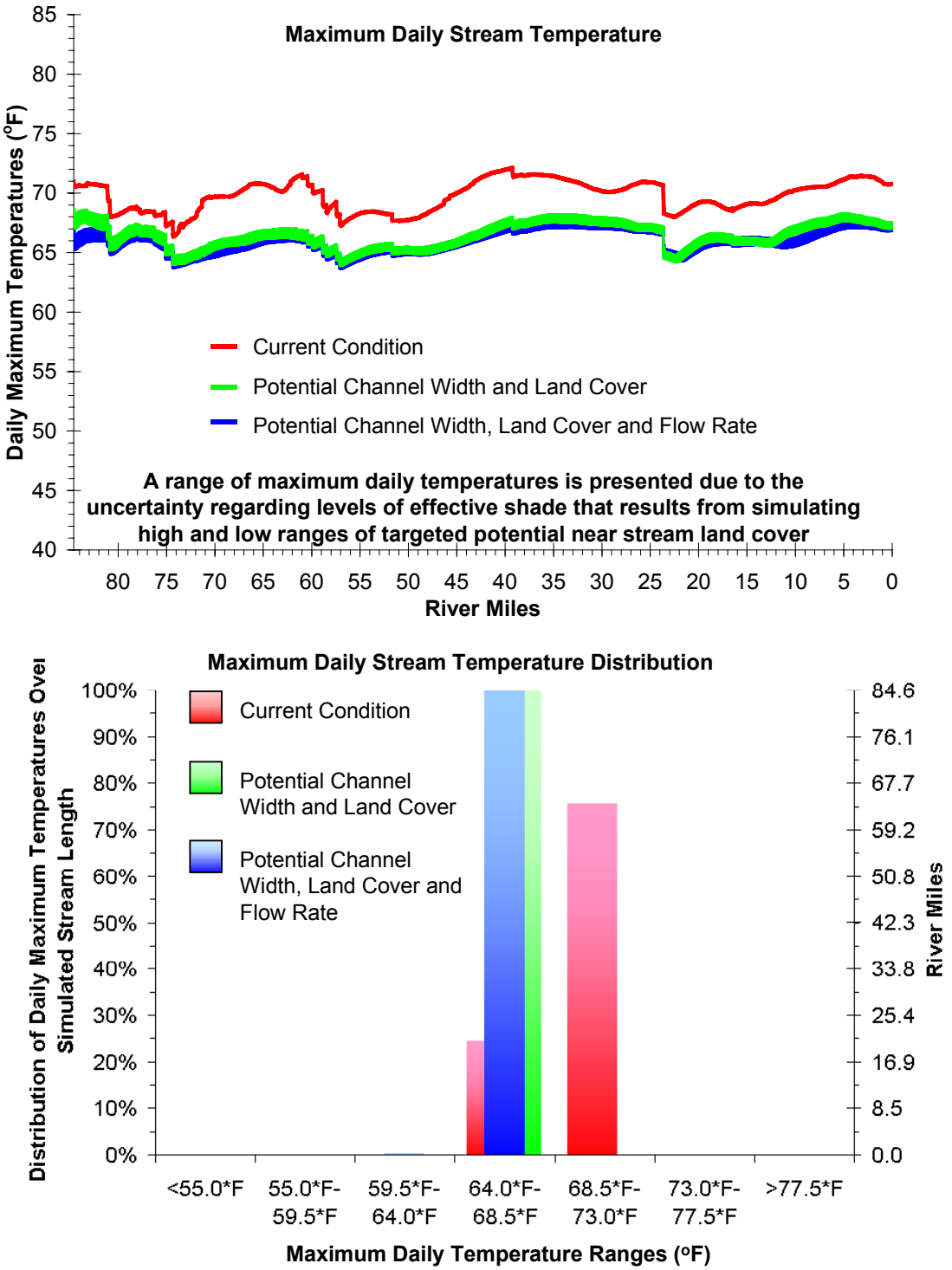


***Figure 4-34**. Sprague River summary of maximum daily simulated potential stream temperatures. Upper chart displays the longitudinal profile of maximum daily stream temperatures. A range is provided showing the range of potential temperatures due to uncertainty related to the potential land cover condition. The lower chart is a histogram that shows the distribution of simulated maximum daily stream temperatures for the current condition compared to potential channel width, land cover and flow rate.*

4.3.2.5 Williamson River Stream Temperature Simulations

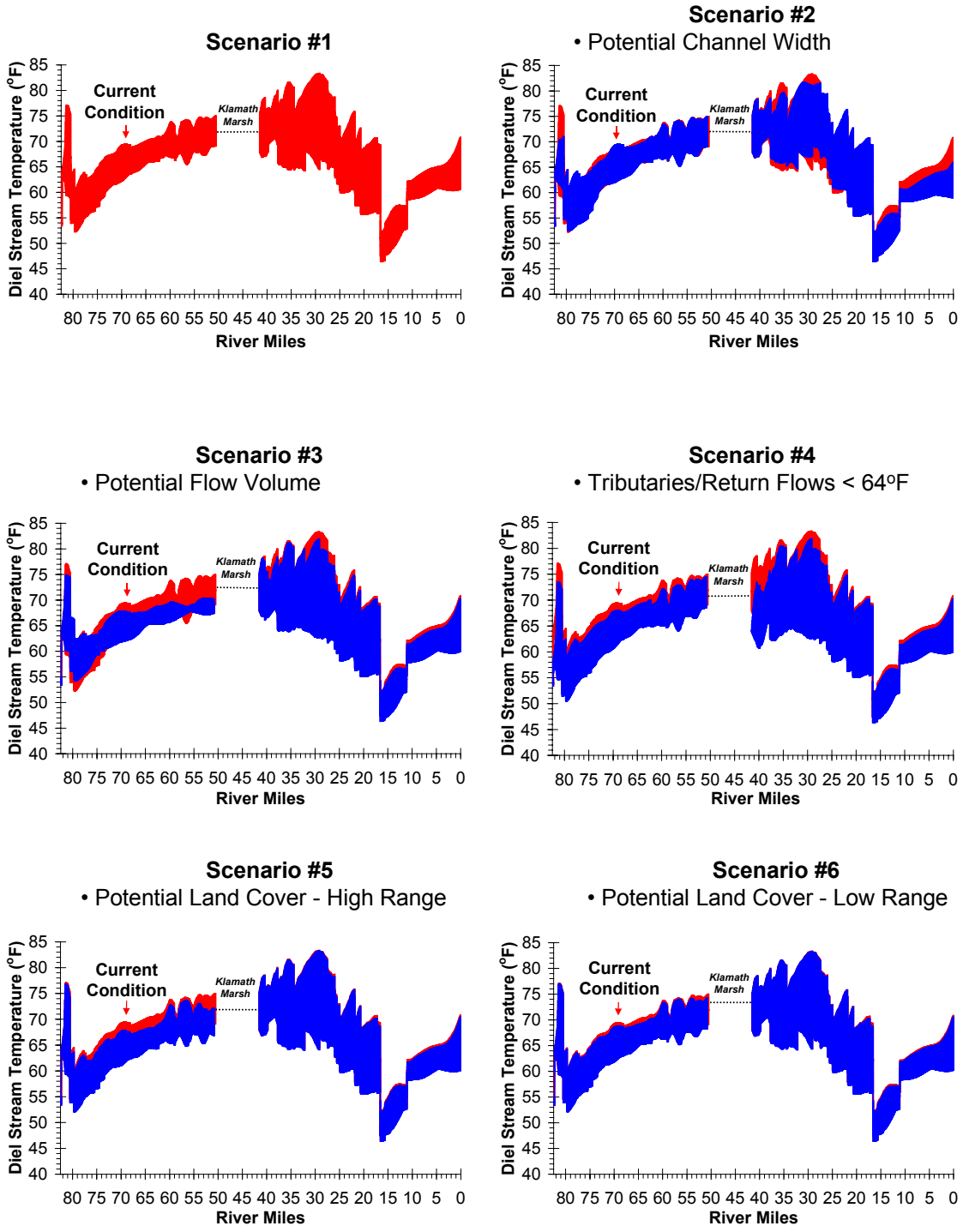


***Figure 4-35**. Williamson River Simulated Stream Temperature Scenarios*

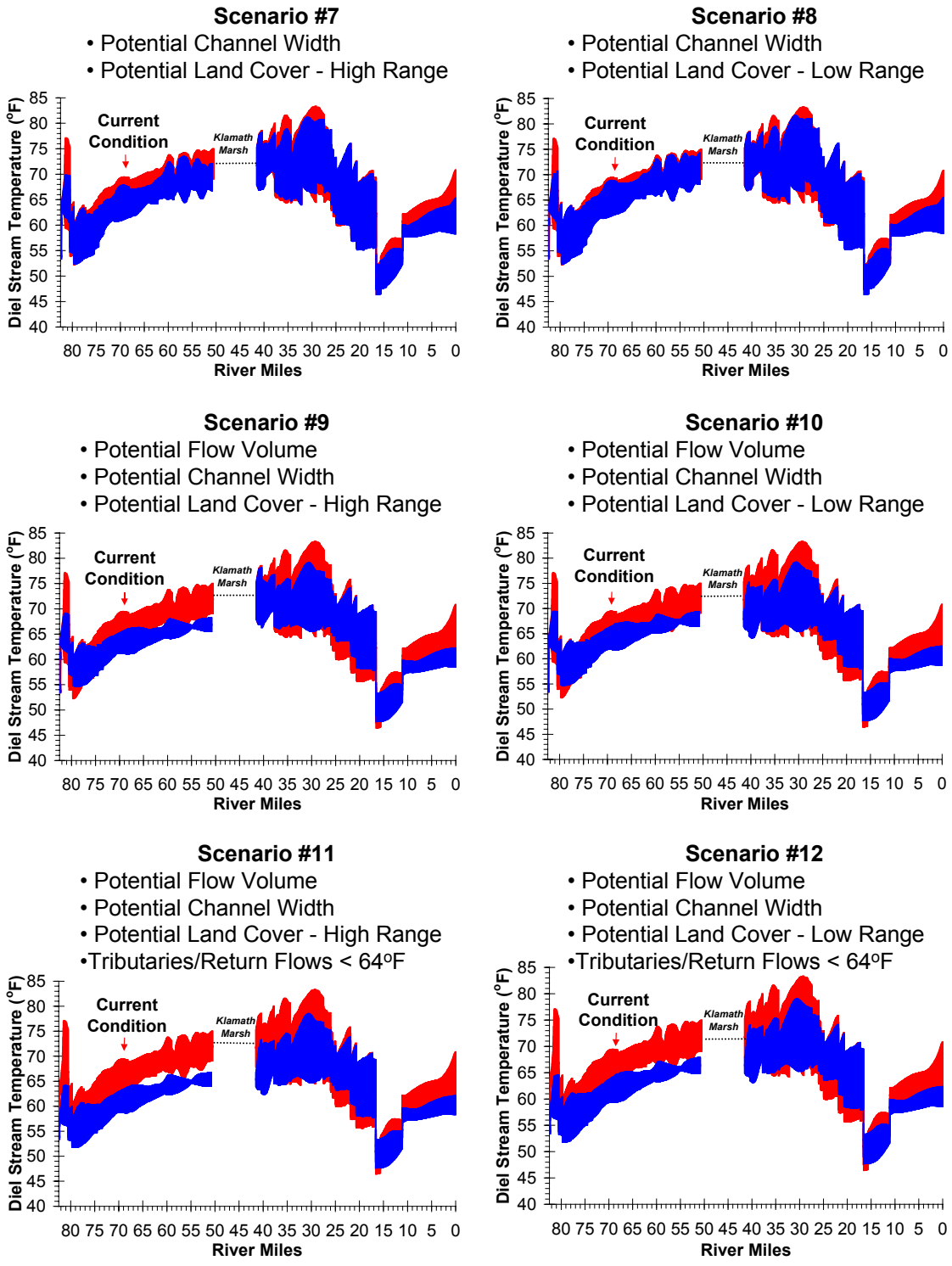


***Figure 4-35 (continued)**. Williamson River Simulated Stream Temperature Scenarios*

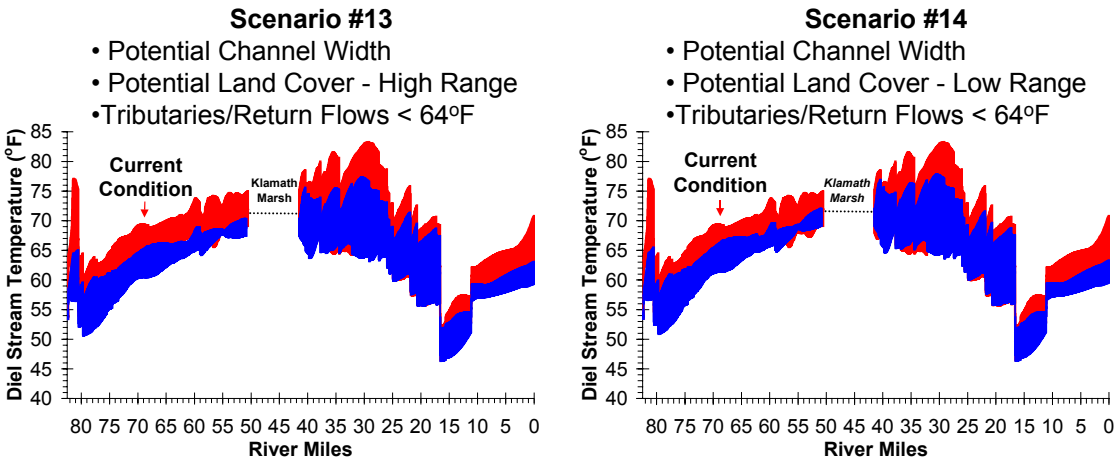


***Figure 4-35 (continued)**. Williamson River Simulated Stream Temperature Scenarios*

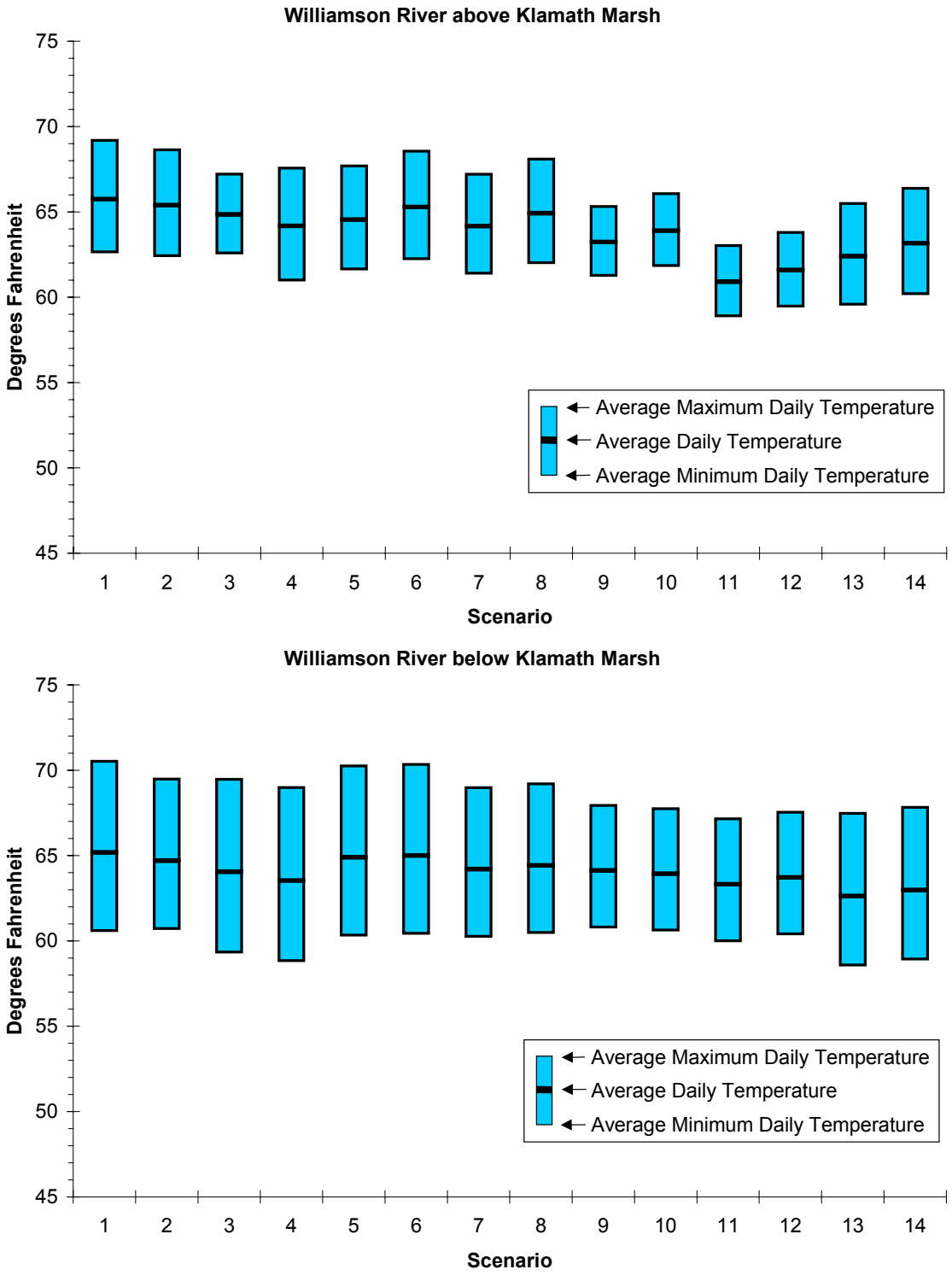


***Figure 4-36**. Williamson Summary Average Simulated Stream Temperature Scenarios. Average values calculated for the entire simulation length (67.6 river miles).*

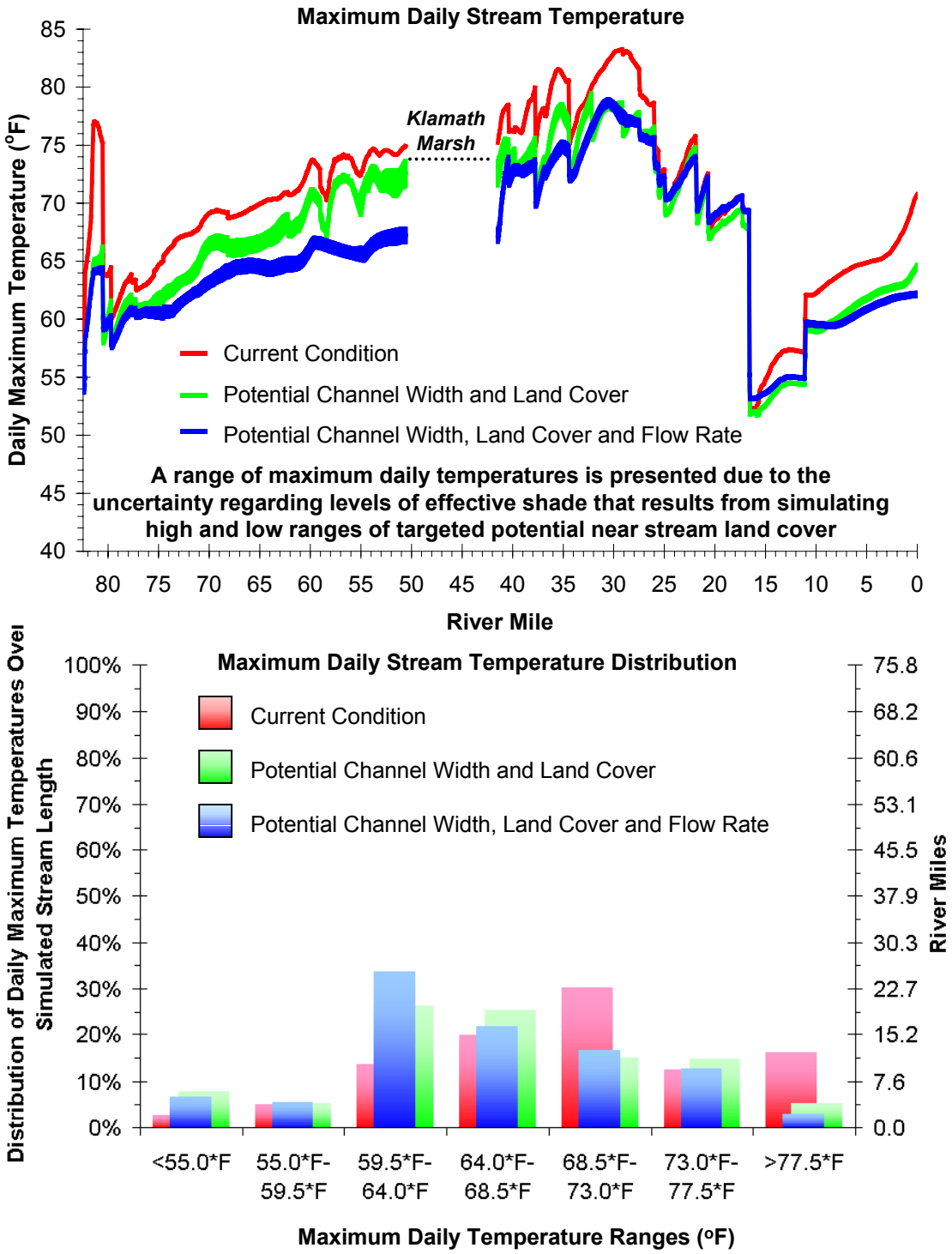


***Figure 4-37**. Williamson River summary of maximum daily simulated potential stream temperatures. Upper chart displays the longitudinal profile of maximum daily stream temperatures. A range is provided showing the range of potential temperatures due to uncertainty related to the potential land cover condition. The lower chart is a histogram that shows the distribution of simulated maximum daily stream temperatures for the current condition compared to potential channel width, land cover and flow rate.*

4.3.3 Stream Temperature Simulations Sensitivity Analysis

In general, the rivers/streams exhibited high levels of sensitivity to potential land cover and channel width reductions and potential flow combinations. Single parameter scenarios that simulated one potential condition while leaving other parameters in the current condition result in smaller temperatures reductions. Largest temperature reductions occur from scenarios that include potential land cover, channel width, flow rates and reduce tributary temperature to below 64°F (i.e. scenarios 11 and 12).

The upper Williamson River and North Fork Sprague River have exhibited the highest sensitivity to system potential conditions. The lower Williamson River and the South Fork Sprague River have a moderate sensitivity to system potential conditions, while the Sycan River and Sprague River have low sensitivity to system potential conditions. **Figure 4-38** displays the sensitivity analysis by evaluating the average stream temperature reduction over the analyzed stream lengths.

Simulated Scenarios

Scenario		Scenario	
1	Current Condition	**8**	Potential Channel Width Potential Near Stream Land Cover – Low Range All other inputs remain unchanged
2	Potential Channel Width All other inputs remain unchanged	**9**	Potential Flow Potential Channel Width Potential Near Stream Land Cover – High Range All other inputs remain unchanged
3	Potential Flow All other inputs remain unchanged	**10**	Potential Flow Potential Channel Width Potential Near Stream Land Cover – Low Range All other inputs remain unchanged
4	Tributaries and Return Flow Temps < 64°F All other inputs remain unchanged	**11**	Tributaries and Return Flow Temps < 64°F Potential Flow Potential Channel Width Potential Near Stream Land Cover – High Range All other inputs remain unchanged
5	Potential Near Stream Land Cover – High Range All other inputs remain unchanged	**12**	Tributaries and Return Flow Temps < 64°F Potential Flow Potential Channel Width Potential Near Stream Land Cover – Low Range All other inputs remain unchanged
6	Potential Near Stream Land Cover – Low Range All other inputs remain unchanged	**13**	Tributaries and Return Flow Temps < 64°F Potential Channel Width Potential Near Stream Land Cover – High Range All other inputs remain unchanged
7	Potential Channel Width Potential Near Stream Land Cover – High Range All other inputs remain unchanged	**14**	Tributaries and Return Flow Temps < 64°F Potential Channel Width Potential Near Stream Land Cover – Low Range All other inputs remain unchanged

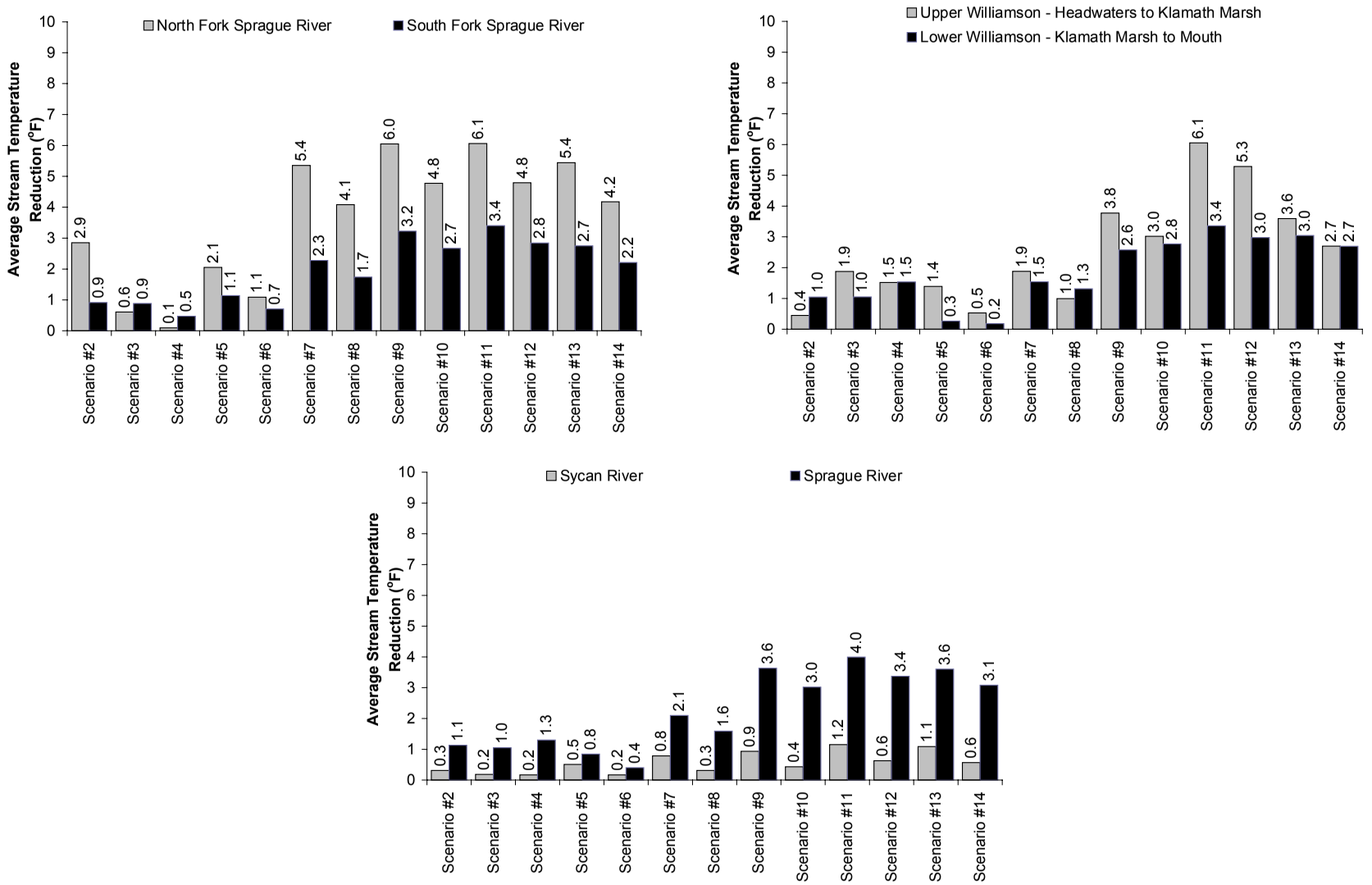


***Figure 4-38**. Stream Temperature Scenarios - Sensitivity Analysis*

4.4 Discussion - Stream Temperature Distributions

Maximum daily stream temperature distributions are presented in **Figure 4-37**. Currently 61% of the sampled stream segments (162 river miles) in the Upper Klamath Lake Drainage exceed 68°F[27]. Under potential land cover and channel width, 17% of the simulated stream segments (45 river miles) exceed 68°F resulting in an additional 117 river miles that remain below this temperature threshold when compared to the current condition. When potential flow volume is added to potential land cover and channel width, 10% of the simulated stream segments (26 river miles) exceed 68°F, resulting in an additional 19 river miles below this threshold condition when compared to the potential land cover and channel width. Results indicate that 83% of the stream length can achieve maximum daily stream temperatures less than 68°F under system potential conditions. With this result comes a reality that 17% of the stream system will remain above 68°F.

An overriding emphasis of this analysis is the focus on spatial distributions of stream temperatures in the Upper Klamath Lake drainage. Comparisons of stream temperature distributions capture the variability that naturally exists in stream thermodynamics. Spatial variability is observed in all of the stream segments sampled and analyzed. With the advent of new sampling technologies and analytical tools that include landscape scaled data and computational methodologies, an improved understanding of stream temperature dynamics is emerging (Boyd, 1996, Faux et al. 2001, Torgersen et al., 1995, Torgersen et al., 1999, Torgersen et al., 2001, ODEQ 2000a, ODEQ 2001a, ODEQ2001b, ODEQ 2001c). This understanding accommodates spatial and temporal variability that includes departures from biologically derived temperature threshold conditions.

Further, simple conceptual models that focus on a single stream, landscape or atmospheric parameter will fail to capture the interactions of a multitude of parameters that are interrelated. These parameters combine to have complex thermal effects. As an example, at a network scale modeling demonstrates that stream temperatures are relatively insensitive to potential land cover conditions. However, when coupled with potential channel width, stream temperatures are highly sensitive to potential land cover. When flow volume is increased to potential, the temperature reductions created by potential land cover and channel width are further increased. **The results of this analytical effort clearly demonstrate that a comprehensive restoration approach should be developed that focuses on the protection and recovery of land cover and channel morphology, and increases instream flow volume.**

[27] The proposed EPA sub-lethal temperature limit for redband trout is 68°F (EPA 2001).

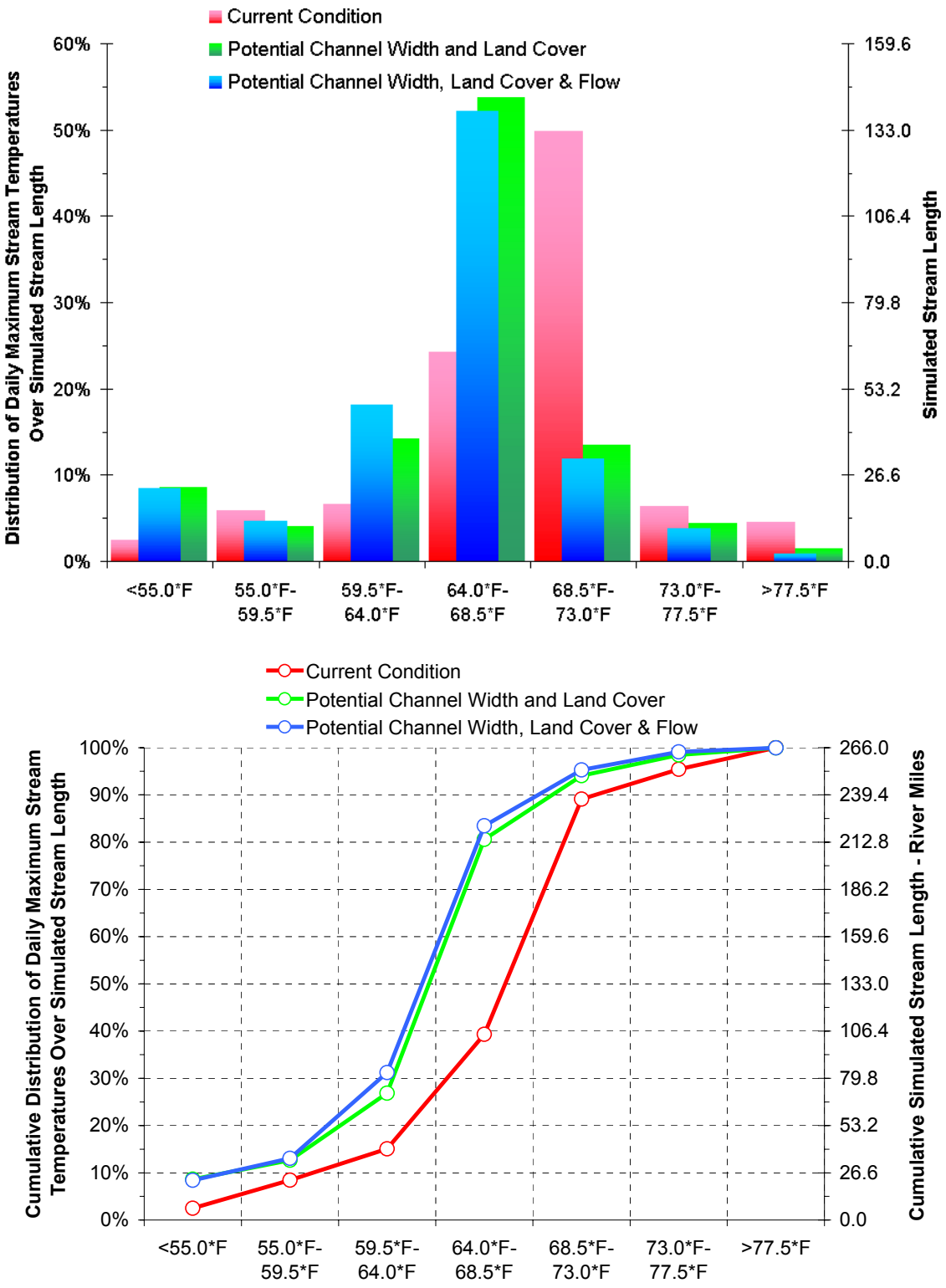


***Figure 4-39**. Distributions of maximum daily stream temperatures in the Williamson River and Sprague River stream network (266 river miles) for current and potential conditions.*

ACRONYM LIST

BLM – Bureau of Land Management

CFR - Code of Federal Regulations

cfs - cubic feet per second

CWA - Clean Water Act

DEM - Digital Elevation Model

DEQ - Department of Environmental Quality (Oregon)

DOQ - Digital Orthophoto Quad

DOQQ - Digital Orthophoto Quarter Quad

EPA - (United States) Environmental Protection Agency

FLIR - Forward Looking Infrared Radiometry

HUC - Hydrologic Unit Code

LA - Load Allocation

LC - Loading Capacity

NSDZ - Near-Stream Disturbance Zone

OAR - Oregon Administrative Rules

ODA - Oregon Department of Agriculture

ODEQ - Oregon Department of Environmental Quality

ODF - Oregon Department of Forestry

ODFW - Oregon Department of Fish and Wildlife

OWRD - Oregon Water Resources Department

R^2 – Correlation coefficient

RM - River Mile

SE - Standard Error

TMDL - Total Maximum Daily Load

USBR (US BOR) - United States Bureau of Reclamation

US COE - United States Army Corps of Engineers

USDA - United States Department of Agriculture

USFS - United States Forest Service

USGS - United States Geological Survey

W:D - Width to Depth (ratio)

WLA - Waste Load Allocation

WQS - Water Quality Standard

WWTP - Waste Water Treatment Plant

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