Surface Water Information Modeling System (SWIMS)

Disturbance Index for Oregon’s Gaged Watersheds

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Executive Summary

This document describes the creation of an index intended to quantify the degree of anthropogenic disturbance to Oregon’s gaged watersheds. The index is intended to identify gaged watersheds collecting streamflow data that can support development of a model to estimate natural streamflow conditions in watersheds with no data or data that is heavily impacted by anthropogenic modification.

The index was created to mimic the GAGES-II (Geospatial Attributes of Gages for Evaluating Streamflow [Falcone, 2011]) data set on a statewide scale. Gaged watersheds used in the development of the index were mainly operated by the Oregon Water Resources Department and the US Geological Survey. Geospatial attributes included in the analysis were based on key variables identified by Falcone (2011) and included dam storage, dam density, surface water withdrawals, irrigated area, fragmentation, road density, and artificial stream pathways.

After summarizing attributes, disturbance scores were calculated to reflect the degree of disturbance relative to other regional watersheds. Oregon watersheds were grouped by region based on their location either east or west of the Cascade Range as there were distinct differences in the degree of disturbance among geospatial attributes. Watersheds were then categorized based on their cumulative disturbance scores: low, low-to-moderate, moderate, moderate-to-high, and high.

Introduction

Stream flow and watershed processes are directly influenced by climate and human activities. Anthropogenic disturbances, including damming operations, effluent discharges, surface water diversions, groundwater abstractions, landscape alterations, and channel modification, can impact stream flow conditions such that the regime no longer reflects its natural patterns. Such modifications can alter the timing, magnitude, and natural variability of stream flow response to typical climate cycles and watershed processes that shape hydrographs (e.g., seasonal, annual, etc.). Many water management and planning challenges are dependent upon a foundation of natural stream flow data that can provide a reference point from which to determine how anthropogenic activities have impacted water supply conditions. Therefore, it is important to determine the nature and degree to which watersheds have been altered and identify those providing reference information.

Data describing stream flow characteristics are obtained primarily from stream gages. While many watersheds in Oregon are currently gaged or have been previously, oftentimes human activities upstream from the gaging location influence the recorded observations. Furthermore, there are many more watersheds that remain ungaged and lack a current or historic period of record and so stream flow characteristics must be estimated, typically using information from nearby gaged locations of reference quality. However, in order to qualify as reference information and be useful in standard hydrologic modeling, the site should be minimally influenced by anthropogenic factors in addition to the natural climate and hydrologic cycle.

In order to design a reference stream gage data set for predicting natural flow regimes across the United States, Falcone et al (2010) developed a hydrologic disturbance index to identify streams and rivers that currently have near-natural flow conditions. Watersheds were assessed for their reference quality based on a quantitative index of anthropogenic modification within the watershed based on a suite of GIS-derived (Geographic Information Systems) variables. Falcone et al (2011) identified a set of key disturbance variables which best differentiated between most and least disturbed sites. Relying on those key disturbance variables, a similar process was employed for this analysis of Oregon's gaged watersheds to be used in developing a reference gage list for summarizing water supply conditions and in future hydrologic investigations.

Gage Screening and Watershed Delineation

Streamgages

OWRD and USGS databases of mean daily flow records were first queried to identify gages measuring stream flow in Oregon with at least three consecutive complete water years of record since 1950. The percentage of each water year with mean daily flow measurements was calculated in order to determine completeness. Gaged water years were considered complete if they had a completeness value greater than or equal to 95% (i.e., no more than 18 missing mean daily flow values). The resulting list was then pared down by removing gages measuring diversions, such as canals and ditches.

Delineated Watersheds

As mentioned previously, gages measuring stream flow in Oregon were selected for this analysis. Watershed boundaries provided the basis for extracting GIS-based information for data processing. Considering there are gages measuring stream flow that originates in headwaters outside of state boundaries, it was important to exclude these gages from further analysis. This was due to the unavailability of coverages of certain Oregon-based data sets, such as water rights information necessary to calculate surface water withdrawals and coverage of irrigated area for each watershed. Watersheds were visually inspected to verify that boundaries aligned with the appropriate stream channel and were corrected as necessary.

Mean Annual Runoff

Mean annual runoff was used to scale some disturbance variables. As many of the gages in this analysis measured streamflow during different time periods, it was desirable to use a value that reflected a common time period. Estimates of mean annual runoff were obtained from NHDPlus V2.1 (2012) via Extended Unit Runoff Method tables for flowline features. The Q0001C variable provided a measure of "natural" flow at the downstream end of the flowline representative of the 1971 to 2000 time period. Flowlines at the outlet of each watershed were selected manually. In instances when no mean annual runoff data was available via NHD, the gaged data was used to calculate mean annual runoff for the gaged period of record.

Calculating Disturbance Variables

Dam Density

Data and information for Oregon dams was acquired from the National Inventory of Dams (NID) database. This data set was used to calculate dam density. The number of dams with no size restrictions was totaled and then divided by watershed area (sqmi) to calculate dam density (nbr dams/sqmi).

Dam Storage

The NID database maintains several variables related to the volume of dam storage. The variable chosen for this analysis was normal storage, defined as the total storage space in a reservoir below the normal retention level. For instance, normally dry dams will have a normal storage value of zero. Dam storage (ac-ft) was then divided by volumetric mean annual runoff (ac-ft; see Mean Annual Runoff).

Road Density

The Topologically Integrated Geographic Encoding and Referencing (TIGER [2019]) database was used to calculate road density. Specifically, the All Roads County-based Shapefile was used because it provides a robust data set of impervious and compacted surfaces, including primary roads, secondary roads, local neighborhood roads, rural roads, city streets, vehicular trails, ramps, service drives, walkways, stairways, alleys, and private roads.

The All Roads dataset contains multiple overlapping road segments where a segment is associated with more than one road feature. For example, if a road segment is associated with US Route 36 and State Highway 7 and 28th Street, the shapefile will contain three spatially coincident segments, each with a different name. To resolve this complication and avoid situations of overlapping polylines, a dissolve procedure was performed on the layer such that only a single line feature would remain. Total road length (mi) was then calculated and divided by watershed area (sqmi) to calculate road density (mi/sqmi).

Artificial Stream Pathways

The percentage of all stream miles considered to be artificial was calculated based on NHDPlus V2.1 flowline features. Length (mi) was calculated for all flowlines to calculate total stream length. The FCode attribute was used to classify flowlines as either natural or artificial. Any feature types (i.e., flowlines) not classified as stream/river (FCode = 46000, 46003, 46006, 46007) were considered artificial. The percentage of flowlines, in terms of total stream length, classified as artificial was then calculated.

Fragmentation Index

The fragmentation index reflects the degree to which the natural landscape has been anthropogenically modified (i.e., fragmented). The National Land Cover Dataset (2021; Dewitz, 2023) provided the base information for deriving this variable. An algorithm developed by Riitters et al (2000) was used to support this calculation. First, pixels in the land cover raster were characterized as developed or undeveloped, where undeveloped included land cover pixels within all non-urban and non-agriculture classes. Open water pixels were given a value of NA and ignored in further calculations. Following this classification, a 3x3 processing window was then used to characterize each center pixel as fragmented or unfragmented based on the surrounding pixels. In order to be considered unfragmented, a given pixel must be completely surrounded by undeveloped pixels. Fragmentation index was then calculated as the percentage of total pixels classified as fragmented, such that higher values represent higher degrees of fragmentation.

Percent Irrigated

OWRD’s Water Rights Information System (WRIS) was used to determine the percentage of irrigated area within each watershed. A GIS coverage of places of use (POU) for mapped water rights was used to calculate the area of each POU polygon. Active water rights were queried to identify those associated with irrigation or agriculture according to the use code characteristic. The query included water rights sourced from both groundwater and surface water, as well as those sourced from reservoir storage. This assessment did not consider supplemental water rights. As some places of use overlapped in the dataset, these features were dissolved to create a single polygon for which the acreage was then calculated (acres). The percentage of the watershed with irrigated coverage was then calculated by dividing the total irrigated acreage by the acreage of the watershed.

Surface Water Withdrawals

Surface water withdrawals were quantified using information in the WRIS database. To begin, only PODs sourced from surface water were included in this assessment – PODs sourced from groundwater were ignored. In order to avoid overestimation, water rights sourced from reservoir storage were excluded because WRIS accounts for stored water in the primary reservoir storage permit. Similarly, surface water rights with a storage use code were also excluded. Water rights were further screened based on their use code to include only those for out-of-stream uses. Water rights associated with use categories that support instream flows were excluded.

After querying for relevant water rights, information related to the volume, duty, and/or rate was used to quantify the volume (ac-ft) of permitted withdrawal for each POD associated with a water right. Withdrawals for irrigation/agriculture were calculated by multiplying the duty by the acreage of the POU associated with the right. Where possible, acreage information was obtained via GIS; however, in situations where GIS information was unavailable, acreage values listed in WRIS were obtained. If no acreage information was available, the right was excluded from further processing. Duty was extracted from WRIS or using location-based information determined by adjudicated areas. Finally, if a water right had a listed or GIS-derived acreage, but duty information was unavailable, an average duty of 3 ac-ft/ac was assigned.

For all other uses (e.g., municipal, industrial, mining, etc.), withdrawal volumes were summarized either using the listed maximum volume permitted to be withdrawn on an annual basis or using rate information listed on the water right. The maximum volume provides an upper limit, but rate-based calculations do not. When using rate to quantify withdrawals, the total annual volume was limited by assuming full use of the permitted rate once per each month of the year. Withdrawal volume was then summarized by use code to assist in further refining quantification of withdrawals. Water rights with the following use code classifications were ignored from calculations: power development, groundwater recharge, wildlife, mining, recreation, fish culture, and manufacturing.

Defining Regions

Gaged watersheds were assigned a region based on their location as east or west of the Cascade Crest. Dividing the state into east and west allowed for computation of the disturbance index by region, a recommendation based on the regionalization approach taken by Falcone et al (2010, 2011). Six total variables were used in calculation of total hydrologic disturbance for each region. The main difference is that fragmentation index was used to describe modifications to the landscape in the west, and percent irrigated was used in the east. This was done based on a high degree of correlation between the two variables in each region, though fragmentation was less associated with irrigation in the west compared to the east.

Calculating Disturbance Scores

Disturbance scores were calculated by region for each variable described above by assigning a value from 0 to 8 points based on their percentile value within the data range for all non-zero records. Since scores were calculated by region, percentiles were calculated for each region separately, such that gaged watersheds west of the Cascades were compared to others in the west and similarly for the east. Increasing point values were assigned according to the 1st (0), 20th (1), 40th (2), 60th (3), 80th (4), 90th (5), 95th (6), and 98th (7) percentiles, where anything greater than the 98th percentile value received a score of 8 and all zero values were assigned a score of 0. Then, those points were summed for the six variables used in each region, providing an index which ranged from 0 (least likely to have hydrologic disturbance) to 48 (most likely). Gaged watersheds were then assigned a qualitative disturbance category based on percentiles of total disturbance scores: 0 to 20 (low), 20 to 40 (low to moderate), 40 to 60 (moderate), 60 to 80 (moderate to high), and 80 to 100 (high).

References

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