Dam Safety in Oregon

This brochure has been designed for dam owners and potential dam owners by the Dam Safety program at the Oregon Water Resources Department (referred to as Department).

It should also be useful for engineers, other dam inspectors, dam construction and repair contractors and any person interested in dam safety in Oregon. This brochure contains general information, along with recommended technical resources on specific topics (with internet links).

Funding for this publication was provided by a Dam Safety grant from the Federal Emergency Management Agency (FEMA)

The dam on the cover is in a very remote location in Malheur County, built by hand almost a 100 years ago, and maintained in excellent condition.
<table>
<thead>
<tr>
<th>CONTENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introductory Information</strong> 3</td>
</tr>
<tr>
<td>- Authorities 4</td>
</tr>
<tr>
<td>- Hazard Classification 5</td>
</tr>
<tr>
<td>- Permits for New Dams 5</td>
</tr>
<tr>
<td>- Dam Safety Database Link 6</td>
</tr>
<tr>
<td><strong>Dam Fundamentals</strong> 7</td>
</tr>
<tr>
<td>- Forces on and in a Dam 7</td>
</tr>
<tr>
<td>- Resisting those Forces 7</td>
</tr>
<tr>
<td>- Engineering Design of a Dam 7</td>
</tr>
<tr>
<td>- Dam Construction 8</td>
</tr>
<tr>
<td><strong>Dam Safety Inspections</strong> 11</td>
</tr>
<tr>
<td>- Rating of Dam Condition 11</td>
</tr>
<tr>
<td>- Dam Structure 12</td>
</tr>
<tr>
<td>- Reservoir Condition 12</td>
</tr>
<tr>
<td>- Drainage and Leakage 13</td>
</tr>
<tr>
<td>- Conduits, Valves and Gates 13</td>
</tr>
<tr>
<td>- Spillway 13</td>
</tr>
<tr>
<td>- Access and Security 14</td>
</tr>
<tr>
<td><strong>Potential Dam Safety Issues</strong> 15</td>
</tr>
<tr>
<td>- External Erosion 15</td>
</tr>
<tr>
<td>- Vegetation 15</td>
</tr>
<tr>
<td>- Animal Damage 16</td>
</tr>
<tr>
<td>- Internal Erosion 16</td>
</tr>
<tr>
<td>- Valve and Conduit Operation 16</td>
</tr>
<tr>
<td>- Safely Passing Flood Flows 17</td>
</tr>
<tr>
<td>- Damage to Concrete 17</td>
</tr>
<tr>
<td><strong>Planning to Prevent Emergencies</strong> 19</td>
</tr>
<tr>
<td>- Emergency Action Plans 19</td>
</tr>
<tr>
<td><strong>Other Important Information</strong> 21</td>
</tr>
</tbody>
</table>
Introductory Information

- Before constructing any **statutory dam** (a dam that is ten feet or higher and stores more than 9.2 acre feet of water) the State of Oregon requires design specifications and drawings prepared by an Oregon Registered Professional Engineer. The State has an alternate application process available for smaller dams.

- Before dam construction, have plans formally reviewed and approved by the Department. When design specifications and drawings are complete and properly submitted the Department will review these in a timely manner. The Department will notify the design engineer to request any additional information.

- Dam owners need to maintain and repair dams as necessary to protect life and property, as well as to avoid wasting or damaging water resources. A small amount of preventative work in inspection, maintenance and repair can increase the life and value of a dam and protect the dam owner and neighbors. The Department has design information to assist this work and can provide it upon request.

- The Department will conduct routine inspections for most dams on a schedule that is based on each dam’s hazard classification. Inspection letters are sent to dam owners. Most dams in the state that are owned by the Federal government or with hydropower permitted by the Federal Government are inspected by the appropriate Federal Agency.

- Dam owners must consult with an Engineer prior to complex repairs or major modifications, such as increasing the height of the dam or altering the configuration of conduits and other infrastructure that penetrates into or through a dam.

- For high hazard dams, an Emergency Action Plan should be completed by dam owners or their representative. The plan should be available as appropriate and updated as needed to reflect current contact information and safety contingencies.

- In recent years there have been very few dam failures in the state of Oregon. This is due in large part to dam owners taking their responsibilities seriously. When dam failures have occurred around the world, damage has often been catastrophic.

OWRD dam safety web link for more information:
https://www.oregon.gov/owrd/programs/streamslakesanddams/dams/
Authorities
The OWRD administers laws and rules governing surface water and groundwater resources. Oregon’s laws, called Oregon Revised Statutes (ORS), authorize and direct the Oregon Water Resources Department to take specific actions related to design and construction of new dams, and the safety of existing dams. The Department has been directed by law to review designs for statutory dams since 1909. Those interested in specific legal language can review the laws and rules at the following web sites:

Oregon Revised Statutes [http://www.leg.state.or.us/ors/](http://www.leg.state.or.us/ors/)
ORS 537.109 to 537.420
ORS 540.340 to 540.545

Oregon Administrative Rules [https://secure.sos.state.or.us/oard/displayChapterRules.action?selectedChapter=183](https://secure.sos.state.or.us/oard/displayChapterRules.action?selectedChapter=183)
OAR 690-020-0000 to 0200

---

*Dam inspection in progress with dam owner and an Assistant Watermaster.*
Over time, there have been many changes in the dam safety program’s responsibilities and staffing. As of September 2011, the Dam Safety Section staff included a dam safety engineer and an intern, with administrative support and the State Engineer at the Division level. Dam safety inspections are also performed by the twenty District Watermasters, and by Assistant Watermasters throughout the state.

Federal agencies like the Army Corps of Engineers, Bureau of Reclamation, and the Federal Energy Regulatory Commission also conduct safety inspections of dams in their jurisdictions. The Federal Emergency Management Agency provides many technical guidance documents and funds to help support the Oregon dam safety program.

**Hazard Classification**

All statutory dams in Oregon are classified by *hazard*. Dam hazard is based on what could happen if the dam fails, not on the condition of a dam. As of August 2011, there were 129 Oregon dams classified as *high hazard*, 196 classified as *significant hazard*, and 1242 classified as *low hazard*. Dam hazard ratings are defined in OAR 690-020-0100 and are described below:

(a) **High Hazard:** This rating indicates that if the dam fails there is a strong plausibility for loss of life. The plausibility is established because of inhabited infrastructure (such as homes and business) downstream that would be inundated to such a degree that it would put the person who inhabits the structure in jeopardy. Any factor that puts a strong probability of people being downstream in an inundation area of a dam failure shall be considered. The department shall endeavor to inspect this class of dams on an annual basis.

(b) **Significant Hazard:** This rating indicates that if a dam fails, infrastructure (such as roads, power lines or other largely uninhabited buildings) would be damaged or destroyed due to inundation and flooding. The department shall endeavor to inspect this class of dams at least once every three years.

(c) **Low Hazard:** This rating indicates that if the dam fails there is little plausibility for loss of life, and human infrastructure that could be affected by inundation downstream is minor or non-existent. The department shall endeavor to inspect this class of dams at least once every six years.

**Permits for New Dams**

There are two different permitting processes for constructing a dam in Oregon. An Alternate Application should be used for *non-statutory* dams that are under ten feet in height or that store less than 9.2 acre feet of water. Applications under this process undergo an expedited review.

Guidance for this process can be found on the Department’s website: [http://www.wrd.state.or.us/OWRD/PUBS/forms.shtml#water_right](http://www.wrd.state.or.us/OWRD/PUBS/forms.shtml#water_right).
Construction of a *statutory* dam requires a primary application for only the storage of a given volume of water, and in most cases a secondary application for use of the water. Before the standard application is approved and a *permit* is issued, the dam must be designed by registered professional engineer and then approved by the Department.

**Dam Safety Database link**
The Dam Safety Program maintains a database of all statutory dams in Oregon. Key elements of this database may be queried by anyone with access to the internet. The database is searchable by dam name, county, watermaster district or region, or river basin. The information provided through this database includes descriptions of each dam including its: height in feet, storage in acre feet, watermaster district, most recent inspection, inspection due date and hazard classification. Additional information includes the dam’s location by: Township, Range, and Section and latitude and longitude.

More detailed design and inspection information can be obtained by emailing the dam safety program staff at dam.safety@wrd.state.or.us.

The Department also maintains hard copy files with engineering information that is useful for dam owners and engineers working on these dams. Drawings and other information can often be provided in digital form.
Dam Fundamentals

Forces on and in a dam
Dams must be designed and constructed to remain stable under forces generated by stored water, flood flows, earthquakes, and other likely disturbances. Water usually needs to pass through a conduit in the dam for a beneficial use at an outlet below the dam. Many floods are expected during the life of a dam. Dams need to pass flood flows without overtopping or sustaining other damage to the dam.

Earthquakes may occur during the life of the structure. Of special note, geologists and the engineering community have now determined that very large earthquakes have been and will be generated by the Cascadia Subduction Zone, just off the coastline. There are also faults throughout much of Oregon, some of which are active and could generate fairly large earthquakes. Earthquakes can create many complex forces within and around a dam.

Water weighs 62.4 pounds per cubic foot. Water pressure increases with depth, so at ten feet deep the water pressure is 10 times 62.4 or 624 pounds per square foot of surface area. The sum of these pressures on all surfaces is pushing against the upper face of the dam. When this water flows into soil or rock below the dam, it will create uplift. Water will seep through most earthen materials and cracks in concrete, causing seepage forces in the dam and or pore water pressure, both of which reduce strength within the dam. The dam must resist all these forces without moving or significantly eroding.

Resisting these forces
Beginning with the base of a dam, its foundation and abutments must be strong. Weak foundation areas must be identified and strengthened. Bedrock often contains joints, fractures or faults that can pose serious safety problems unless identified and properly treated. Earthen and rock embankments can slide if they are too steep. Material in the dam must restrict the flow of water through, around and under the dam. The water that does make it through the dam needs to be drained properly so that it does not destabilize the structure.

Engineering Design of Dams
All large (statutory) dams must be designed to the current standards of engineering practice. Engineers in charge of design work on dams need to have specialized experience and must be registered in Oregon. Dam owners should ask prospective engineers for references on previous work performed that is similar to the dam owner’s project needs. General information on drawings and specifications for engineers in Oregon can be found on the Department’s website.
Because all dams are constructed differently and require engineering judgment, the Department has no rigid template for engineering design requirements. High and significant hazard dams need to be designed for current seismic loadings, as should low hazard dams where zoning will allow development downstream. Where required, fish passage and fish screens must be designed and installed so that they do not compromise dam safety. Engineers must send three copies of the drawings and specifications, plus one set of mylars or other reproducibles directly to the Dam Safety Engineer. When conditions change, engineers should adjust plans and submit these changes in “as-built” drawings to the State Engineer. These drawings and specifications are maintained at the Department and are available should issues with the dam ever develop.

_Cutoff trench as excavated through weak materials and ready for inspection_

**Dam Construction**

Geotechnical (soil and rock) investigation is a critical part of the design. The following specifications must be followed during construction:

- All materials containing roots or other organic material must be stripped and removed from the dam site.
- It is important to excavate a cutoff (key) trench to stronger and tighter soils or rock. This key trench is an integral part of the dam, allowing essential inspection to ensure a solid foundation.
- Soft sandy material is especially susceptible to liquefaction during earthquakes, and must be removed or treated with special engineering techniques.
- The project engineer, and, when possible, the State’s Dam Safety Engineer, need to inspect the key trench during its excavation.

Larger dams also need a core of low permeability materials. Some smaller dams use a material that can act as a core for the entire dam. The core keeps the high seepage and uplift pressures on the reservoir side of the dam. Soils used as filter material around the core and sometimes conduits have very specific gradation (particle size) requirements. All soil and rock used in dam construction need to be compacted to design specifications, and this begins with proper moisture content. Compaction standards are found in all designs, and it is essential to dam safety that these be followed precisely.

The spillway is critical to dam safety. It is always best if the spillway can be excavated into rock off to the side of the dam and not where it could erode dam embankment material. Conduits through the dam must be properly treated so seepage does not flow next to the pipes and cause internal erosion. Conduit materials must be designed to last. Corrugated metal culverts tend to wear out quickly. Encasing conduits in concrete has been a very effective and simple design technique. When unexpected materials, springs, farm tiles or other conditions are found, design modifications may be appropriate. Any changes must have the approval of the project engineer and must be documented.
Dam Safety Inspections

It is essential to inspect dams to ensure continued safe operations. Routine inspections are best when the reservoir is full and again when the reservoir is empty. Seepage and debris issues are most apparent when the reservoir is full, while upstream slopes and inlet works can only be fully inspected when the reservoir is empty. Special inspections are useful during floods to ensure the spillway is handling flow, and after earthquakes to look for changes in the dam. A full inspection covers all faces of the dam (upstream, downstream, crest, abutments and toe), condition of the reservoir and natural slopes above the reservoir, the spillway, all exposed conduits and control works, drains, and security and access. Most inspections conducted by the Department are routine and not flood or emergency condition-related inspections.

Each relevant feature that can be observed or otherwise inspected is given a rating on a scale of 1 to 5 as summarized in the next Table and the following sections. The current inspection form can be found online.

Table 1: Rating of Dam Condition

<table>
<thead>
<tr>
<th>Rating</th>
<th>Meaning</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td><strong>Very Good condition</strong></td>
<td>Properly functioning, clean and clear</td>
</tr>
<tr>
<td>4</td>
<td><strong>Adequate Condition</strong></td>
<td>Able to observe function, average condition</td>
</tr>
<tr>
<td>3</td>
<td><strong>Needs maintenance or minor repair</strong></td>
<td>Function slightly affected or likely to be affected before next inspection; or function unnecessarily obscured</td>
</tr>
<tr>
<td>2</td>
<td><strong>Serious repair needed</strong></td>
<td>Not functioning properly and likely to compromise dam safety</td>
</tr>
<tr>
<td>1</td>
<td><strong>Urgent dam safety issue – action now</strong></td>
<td>Critical dam function not working, dam failure possible under current operations unless changed</td>
</tr>
</tbody>
</table>
Overhead (plan) view of dam and reservoir showing important locations for inspection

**Dam structure**
Most dams in Oregon are made of soil, some are rock-fill, the largest dams are often concrete, and there are also a few masonry structures. There are some differences in a dam inspection depending on the structure type. It is critical to evaluate conditions of the upstream face, downstream face, left and right abutments (left and right as you are facing downstream) and the toe of the dam. The inspector should look for and identify excess vegetation, animal burrows, erosion and seepage.

**Reservoir condition**
The inspection should document the following:
- What is the current water level in relation to a staff gage, the crest and/or base of spillway?
- Where is the debris line compared to crest (shows the recent highest water level)?
- Has the State Engineer established a water level restriction (water elevation) for the dam? Is the water level at or below the restriction level?
- Is debris floating in the reservoir, or is the watershed prone to debris build-up?
- If debris is present, is it handled and kept away from the spillway and inlet works?
- Have landslides or serous erosion occurred next to the reservoir, and if so, are these under control?
Drainage and leakage
Many dams have drains, often in the toe of the dam, the base of the abutments, or around the outlet works. The water from these drains should be observed during the inspection. And if there is a lot of drainage water, weirs are very useful to detect changes in flow rate. It is important the drains be kept clean and not restrict flow. When the drains become blocked, water may be forced up into dam, causing water to flow out of the toe or other location. It is critical to detect increases in drainage that are not associated with increases in the water level in the dam. The most serious condition is increased and muddy drainage.

Dams may also have instruments such as peizometers, slope indicators and strong ground-motion detectors installed to detect developing problems. For the most part, these need to be checked by trained technicians and engineers. When Department staff perform an inspection they review monitoring data provided to the dam safety engineer.

Conduits, valves and gates
Inspections of water pipes and their controls evaluate the following features:

- Type of control – usually the gate valve is controlled by a manual stem and wheel, or a power assisted device;
- Type of inlet – The inlet is frequently submerged, unless it is a trickle tube or the reservoir is empty, so many inspections do not include the inlet;
- Trash rack – The trash rack keeps debris out of the inlet, and is submerged when water is in the reservoir - when the reservoir is empty note if a trash rack is present, absent, or affected by debris;
- Conduit diameter and outlet condition are best observed at the toe of the dam;
- Valve operation and function – Are valve/gate stems greased, and can the gate or valve be opened? When was the last cycling of the valve? Is the valve wheel covered in dirt, or clearly in disuse?

Spillway
Functional spillways are absolutely essential for dam safety. Inspection determines if the type of spillway is uncontrolled, flashboard, or (on some larger dams) gate controlled. Good condition of both the spillway approach and discharge areas is critical. Any encroachment on these areas by vegetation, roads, erosion or debris is a potential dam safety issue. In larger dams, or those with steep spillways, a stilling basin may be present. If so, it should be inspected for proper energy dissipation. Some dams have a secondary or auxiliary spillway for the highest flows. If present, their approaches must be clear.
Access and Security
The ability to get to a dam if there are unusual conditions is important. An all weather road nearby will allow timely inspections and movement of heavy equipment if needed. It is also important to protect dams from persons that may cause the dam harm, and to protect people from accessing areas where their safety may be compromised. Are fences and signs present and effective? For large, high hazard dams and other dams where people are frequently present, closed circuit cameras can detect problems with the dam, as well as identify if people are in locations where they should not be. Remote low hazard dams generally are less of a security risk and risk to persons.
Potential Dam Safety Issues

External Erosion
Earthen dams are subject to erosion, and unless treated, it worsens over time. The crest is vulnerable to loss of height due to trampling by livestock and vehicle traffic. Maintenance needs to restore the original crest elevation. In addition, a lift of gravel can greatly reduce or eliminate this erosion.

Upstream slopes of reservoirs are subject to wave erosion. Rock armoring can be installed to control significant wave erosion. Headcutting, or an eroded steep drop in a channel sometimes occur in spillways. If left uncontrolled the damage can work back towards the reservoir. Properly installed rip rap can reduce headcutting. Most serious are cracks and dropping of a dam face, or evidence of water flowing over the crest of the dam. Both conditions can lead to an uncontrolled dam breach.

Vegetation
Vegetation can reduce the potential for surface erosion. However, woody vegetation has roots that penetrate into the dam, and these roots will eventually die and provide a path for seepage though the dam. All trees eventually die or blow over. When this occurs, dam integrity is reduced. Trees close to the crest of a dam or near the spillway are especially dangerous and should be removed as soon as possible. Vegetation also provides a home and cover for burrowing animals. The best vegetative cover on a dam is short grass or other non-woody vegetation. This type of cover reduces surface erosion and protects dam surfaces adequately. A good reference for this information is located at:
http://www.fema.gov/library/viewRecord.do?id=1451

Vegetation and debris blocking spillway. Note boots for scale
Severe damage from nutria burrowing into a dam that required major dam reconstruction.

Animal Damage
Burrowing animals can damage embankment dams. Large burrows can penetrate dams, at minimum resulting in significant water loss and repair cost, and can sometimes even lead to a rapid and dangerous dam breach. In Oregon, nutria, badgers, beavers, and muskrats can burrow deep into dams and cause the most damage. An excellent document on animal control can be found here: http://www.fema.gov/library/viewRecord.do?id=1441

More natural and less expensive control (for the smaller animals) can often be achieved by keeping vegetation low and providing perch sites for hawks, owls and eagles. However, small reservoirs are ideal habitat for nutria (a large, invasive, non native rodent). Nutria burrows are especially damaging to earth dams. Nutria have few predators, so it is essential to remove nutria from reservoirs.

Internal erosion
Some seepage occurs at most dams, and the rate of seepage can increase gradually with reservoir level. If the flow rate increases quickly, or is not associated with an increase in reservoir level, this is a sign of dam distress. Muddy water or sediment in the water (not from storm runoff) is a sign of likely serious internal erosion. This may be a very serious and urgent dam safety issue, and can progress rapidly to a sudden dam breach.

Valve and conduit operations
Gates and valves that stick may be signs that valves need to be repaired or replaced. Once opened, valves that have not been cycled in a long time may not close.
Repairs to these valves in the fall will result in the lowest potential for water loss, and allow for refilling during the wet season. If the owner does not wait too long, worn out conduits can often be relined. The Department does have a camera that can be used to evaluate internal erosion leaking into conduits. The options for relining conduits are technical in nature, and an engineer should always be consulted for this work.

Safely passing flood flows
Earthen dams cannot withstand overtopping. This is the most common cause of catastrophic dam failure and loss of life downstream from the dam. Except in the most extreme flood, water level should not approach the top of the dam. If it has or does, the spillway should be improved. Note that even small vegetation can cause debris to build up and reduce essential spillway capacity. For dams that use flashboards to increase summer storage, the boards need to be sturdy. If there are decayed flashboards they need to be replaced. Most importantly, flashboards need to be installed after and removed before the wet season.

Damage to Concrete
Most concrete will spall and crack slowly over time. This type of aging is expected, and as long as the cracks and spall are small or shallow they are usually not an issue. Small leaks are also common in older concrete dams. If these leaks increase in volume it is prudent to have an engineer evaluate them. Some damage to concrete may be hidden. Water flowing down steep spillways can create forces similar to suction, which can cause severe distress to concrete, especially at the edge of individual slabs. Finally earthquake damage is often concentrated where concrete rests on soil or other weaker material, especially around concrete spillways on earthen or rockfill dams.

Cycling the control valve at least once per year helps ensure the valve stays operational.
Planning to Prevent Emergencies

Dam emergencies can be caused by events that reduce stability in the dam. A large snowpack, heavy rain or a combination can cause extreme floods that exceed spillway capacity. Worldwide, earthquakes have caused a number of dam failures. A Cascadia earthquake may be fairly similar to the recent March 2011 Tohoku Japan Earthquake, with the greatest impacts occurring closer to the coast.

Prior to a large flood or when there is an unusual snowmelt, it is important to ensure that dams are not overfilled; it may be prudent to lower water levels in advance of high flows into the reservoir. There is almost always warning of extreme floods, and even more time to prepare for a large snowpack. Earthquakes usually occur with no warning, so it is essential to prepare based on proximity to areas that have a geologic record of large earthquakes. It is also important to inspect a dam after earthquake shaking. Concrete spillways can be subject to serious damage after extreme floods and earthquakes, and dams located on weak foundation materials are also vulnerable.

Dam emergencies can also be caused by conditions within the dam. These problem conditions can often be determined by inspections, or by review of design and specification documents. Temporary or permanent restrictions on maximum water levels are sometimes essential until problem conditions are repaired.

Emergency Action Plans (EAP) identify potential emergency conditions at a dam and preplanned actions to minimize loss of life and property damage. They are plans for unlikely but reasonably possible situations. They are very strongly recommended for all Oregon dams classified as “high hazard.” The EAP should contain six basic elements:

1) Notification Flowchart;
2) Reasonably possible modes of failure and their detection and evaluation;
3) Responsible Parties;
4) Actions that will prevent or reduce severity of problem(s);
5) Inundation maps; and
6) Appendices.

Additional information on Emergency Action Plans is found at the Oregon dam safety website (on page 21).
Other Important Information

Contacting the Oregon Dam Safety Program
Keith Mills, P.E.
Dam Safety Engineer 503 986 0840
Keith.a.mills@state.or.us

The Oregon Water Resources Department's dam safety website is:
https://www.oregon/owrd/programs/streamslakesanddams/dams/

You can find the following information at this website:

- Access to the database
- Current inspection forms
- Terminology
- Guidance for completing Emergency Action Plans
- Photo gallery

Permits from the Department and other agencies are required for certain activities. More information on water rights permits can be found at https://www.oregon.gov/owrd/programs/waterrights/permits

Some, not all of the other agencies that might require permits are listed below:

DSL & USACE for Fill and Removal: http://www.oregon.gov/DSL/
DEQ (treatment lagoons): http://www.oregon.gov/DEQ/
ODA (confined animal feeding lagoons): http://www.oregon.gov/ODA/

Counties sometimes require grading or other permits, and there may be other permit requirements that apply to your project

Sources of Additional Information: The following are agencies or organizations with additional technical information. The first two have more information relevant to dam owners, while the other two contain more information for engineers.

Federal Emergency Management Agency (FEMA)
http://www.fema.gov/
Association of State Dam Safety Officials (ASDSO)
http://www.damsafety.org/
USDI Bureau of Reclamation http://www.usbr.gov/
Federal Energy Regulatory Commission (FERC)
http://www.ferc.gov/