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Flow Deflectors to Reduce Abrasion Damage in Stilling Basins – 40 Year Progress Report

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Mission Statements

The U.S. Department of the Interior protects America’s natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

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Concrete abrasion damage is a common issue at many stilling basins that provide energy dissipation below spillways and river outlet works at Reclamation dams. Sand, gravel, and rock mixed in turbulent flows within the basin cause ball milling damage to the concrete floor and wall surfaces. This literature review summarizes multiple physical hydraulic model investigations performed at Reclamation's Hydraulics Laboratory in Denver, Colorado to identify the flow conditions that lead to abrasion damage, and to develop flow deflector designs for installation on Reclamation projects. Model studies showed, and field installations have verified, that flow deflectors can be effective for eliminating recirculating flow patterns over the end sill of stilling basins. This minimizes the transport of damaging material into basins and promotes flushing of materials from basins. A newly updated inventory of Reclamation stilling basins identifies several facilities that could potentially benefit from flow deflectors.</td></tr>
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Flow Deflectors to Reduce Abrasion Damage in Stilling Basins – 40 Year Progress Report

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Executive Summary

Abrasion damage to concrete surfaces is a recurring issue in many spillway and outlet works stilling basins associated with Bureau of Reclamation dams. Construction materials, trash, wooden and metal debris, sand, gravel, and rock enter the basins either from downstream areas due to normal hydraulic action of the flows within the basin, or by human activities when members of the public throw materials into the flowing water. Once in the basin, these materials are not readily swept out during most flow conditions, so they are churned continuously by turbulent flows within the basin, causing ball milling damage to the concrete surfaces of the basin floors and walls.

The objectives of this project were to review and summarize current knowledge of causes and solutions for stilling basin abrasion, and to assess the current scope and extent of the problem at Reclamation facilities. Two primary tasks were undertaken. First, a review is provided of multiple physical model studies performed over the last 40 years in Reclamation's Hydraulics Laboratory in Denver, Colorado, and accompanying field installation and testing of structural solutions in the form of flow deflectors. This review demonstrates how the results of these studies can be applied today, and identifies knowledge gaps that remain. Second, an inventory of Reclamation stilling basins and associated abrasion problems was assembled and projects that could benefit from stilling basin deflectors were identified. This review of stilling basin abrasion problems is similar to a previous inventory assembled by Zeigler (1978) in association with the first laboratory studies of the problem.

Early laboratory studies were performed with the goal of understanding the flow conditions and the stilling basin abrasion damage process, and later studies focused on the development of deflectors that can modify the flow conditions to reduce or eliminate the problem. Most stilling basin abrasion problems occur in basins that exclusively serve low level outlet works regulated by high pressure slide gates, or combination basins serving both spillway flows and outlet works flows. Most of these basins are either Reclamation Type II or Type III stilling basins, as defined in Engineering Monograph 25 (Peterka 1984). Outlet works flows are typically the most common source of abrasion problems, since they can involve frequent and sustained operation at discharges well below the design discharge of a basin. Low flows make it impossible for a standard Type II or Type III basin to self-clean, and the low-flow condition promotes the churning action that causes damage. In contrast, spillway flows are usually less frequent and less sustained.

The most successful modifications studied in the lab are flow deflectors that help to create self-cleaning flow conditions at lower discharges, but these have generally been limited to use in basins that are 25 ft wide or narrower, since deflectors in very wide basins must withstand extraordinary hydraulic loads.

Three approaches to deflector design are provided in the studies completed to date:

1. Determine deflector size and location based on field measurements of velocity profiles over the end sill of the existing basin. This is the Standardized Deflector Design described in Hydraulic Laboratory Report HL-2015-04. In a Type II basin this may

consist of one deflector or two. For a Type III basin this will always require only one deflector.

2. Determine deflector size and location based on measurements of velocity profiles over the end sill of a basin in a physical model. HL-2015-04 gives several case studies of this approach. This method may involve adjustment of incoming flow velocities in the model to overcome scale-effect distortions, as described in HL-2011-06.
3. Determine deflector size and location using only the basin dimensions and past experience (i.e., without conducting field velocity surveys or building and testing a physical model). This is the Simplified Oversized Deflector Design described in the appendix of HL-2015-04. The method is based on limited physical model tests and is not well proven at this time. This may be a fruitful area for further research.

Several field installations have been completed to date based on physical model testing and field measurements. These installations have all been successful in a practical sense (little subsequent abrasion damage), but there have been some notable differences in velocity profiles over the basin end sill for the field installations and scale models. Whether these differences materially affect the determination of a successful deflector design is uncertain, as is the mechanism by which the physical models fail to accurately represent the field velocity profiles. A scale effect causing overestimation of energy losses in the models is suggested (Hanna 2011), but it is also possible that a scale effect causing underrepresentation of air entrainment is responsible. Hanna (2011) presents an empirical method for adjusting the model discharge to obtain better velocity agreement. Experience with application of this method is still very limited, so it should be applied cautiously.

One technique that has not yet been applied to the stilling basin deflector problem is computational fluid dynamics (CFD) modeling. This approach has promise, but may also prove difficult to successfully apply because of uncertainties about computational modeling of two-phase air and water flows (air entrainment).

To determine the current condition of Reclamation stilling basins, the study assembles an inventory of Reclamation's Type II and Type III spillway, outlet works, or combined spillway and outlet works stilling basins, focused especially on those with widths of 25 feet or less. The inventory was developed starting from a previous compilation by Zeigler (1978), and incorporating newer stilling basins identified in Reclamation project records. In some cases basin dimensions were obtained or verified from aerial imagery such as Reclamation's Tessel8 system. The condition of stilling basins was evaluated through a review of dive reports and other inspections obtained from Reclamation's DSDams system and other sources.

A total of 91 stilling basins were included in the inventory, with the majority serving to dissipate energy from outlet works or combined spillway and outlet works flows. Two of these Reclamation basins have been modified with flow deflectors (Mason Dam and Choke Canyon Dam), and no longer report any debris or damage in the basin. For the remaining 89 facilities, rocks or sediment were reported in 83 percent of the basins, and abrasion damage was reported for 64 percent. Exposed rebar was present in 22 percent of the cases and 15 percent (13 basins) have undergone repairs. A subjective consideration of all of the compiled information led to 44 basins being identified as possible candidates for future flow deflector installation. Managers of these facilities should be contacted for follow-up.

Literature Review

Identifying the Problem

The first focused study of the stilling basin abrasion problem was by Zeigler (1978), titled "Abrasive Materials in Stilling Basins". He performed a computerized keyword search of library databases, but identified only one useful document, an ICOLD (International Commission on Large Dams) conference paper by Arthur (1967) that was focused on abrasion problems in Bureau of Reclamation spillway stilling basins. The paper alluded to increased problems in basins that also served outlet works facilities and also discussed problems with hollow jet valve stilling basins, but did not focus on the narrow Type II and Type III basins that often serve outlet works facilities separate from a spillway. Arthur's general description of the problem was as follows:

> "Bureau of Reclamation experience with spillway hydraulic jump basins has shown that considerable damage can occur to concrete surfaces from debris present in the hydraulic jump. This debris is mainly rock which has fallen into the basin from adjoining slopes, has been thrown in by visitors, or which has been drawn in from the outlet channel by the reverse currents present in the jump. The damage consists of erosion of the floor, walls, and of the dentates.
>
> The severity of damage depends on a number of factors, one of which is the frequency of use. For some projects the outlet works is designed to utilize the spillway stilling basin, to save the cost of a separate energy dissipator. This may result in frequent use of the spillway stilling basin and increase the changes of erosional damage if other unfavorable conditions exist." (Arthur, 1967)

To better define the nature and scope of the problem, Zeigler assembled an inventory and survey of issues at Reclamation stilling basins. He began by considering a wide range of Reclamation facilities, but narrowed the search to a total of 114 stilling basin facilities associated with storage dams. The water releases served by each basin were noted, either spillway, outlet works, or combined spillway and outlet works. Four degrees of severity for abrasion problems were noted: 1) rocks found in the basin; 2) abrasion damage noted in inspection reports; 3) exposed rebar noted in inspection reports; and 4) repairs made to the basin. The information was gleaned from underwater inspection reports (dive reports), review of maintenance program reports, travel reports, and other correspondence (Zeigler, 1978). Zeigler concluded that the most serious issues were in Type II and Type III stilling basins used for high head slide gate-controlled outlet works or in combined outlet works and spillways. Problems were less frequent when stilling basins were used solely for spillway flows. (A notable case in the latter category is the stilling basin at Folsom Dam, which has experienced abrasion damage and was studied in a physical model by Einhellig [1999]).

Standard designs for Reclamation Type II and Type III stilling basins were developed for high head dam spillways and outlet works, as documented in Engineering Monograph 25, first published in 1958 and slightly revised several times since (Peterka 1984). The Type II basin (Figure 1) includes chute blocks at the upstream end and a dentated sill at the downstream end.

The Type III stilling basin (Figure 2) uses a solid end sill with mid-basin baffle blocks that help to shorten the length of the hydraulic jump to create a more compact basin. Type III basins have typically been applied for unit discharges less than 200 $ft^3/s/ft$ and incoming velocities less than 50 to 60 ft/s, but recent baffle block designs that are resistant to cavitation damage have made it possible to apply this type of basin to higher flows (Frizell 2009).

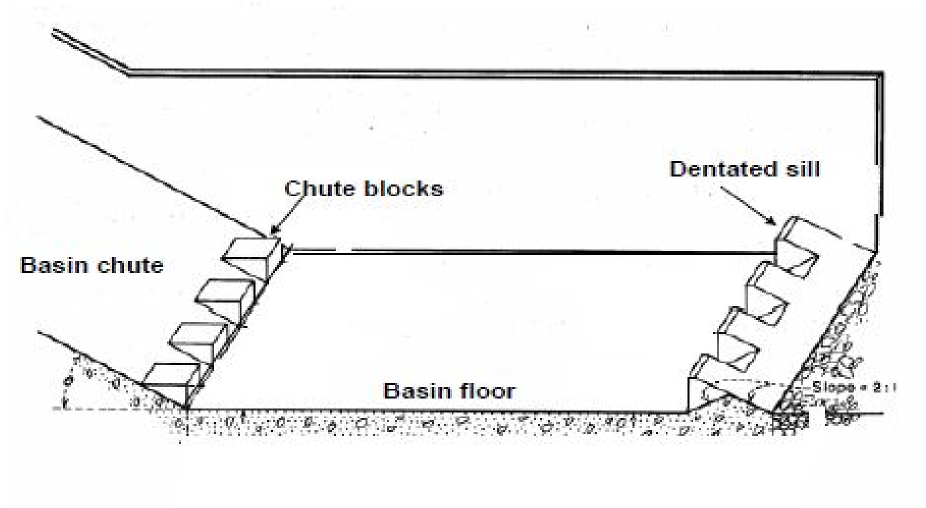

Figure 1. — Reclamation Type II Stilling Basin

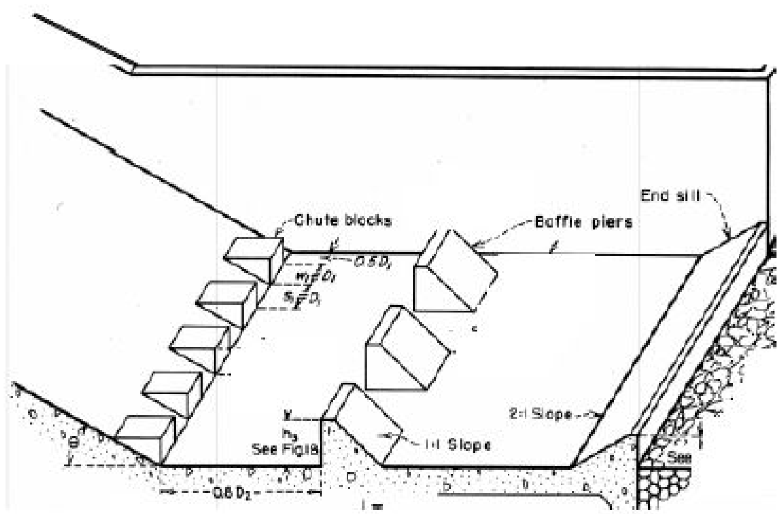

Figure 2. — Reclamation Type III Stilling Basin

Physical Modeling of the Flow Condition

Following Zeigler's initial survey, a 1:8.25 scale physical hydraulic model was constructed and tested in Reclamation's Hydraulics Laboratory in Denver, Colorado to study the flow conditions leading to abrasion damage. The modeled facility was the outlet works stilling basin at Mason Dam, constructed on the Powder River in Baker County, Oregon in 1968. The structure was a standard Type II basin with twin bays. Twin bay basins are common in Reclamation and consist of two identical basins that are parallel to one another, divided for most of their length by a splitter wall, with each side of the basin serving one outlet gate and discharging to a shared tailrace channel. Underwater examinations had shown that the basin's concrete floor was abraded with exposed rebar, and field tests had demonstrated that there was rock movement into the basin from the downstream channel. Basin repairs had been made in 1976.

A short film documenting the study (Zeigler 1982) contained footage of the physical model under various operations of the outlet works at multiple tailwater levels. The testing showed that at some flow conditions the hydraulic jump and the high velocity jet directed downstream along the floor of the basin do not extend over the full length of the basin (Figure 3; Hanna 2010). This is most prevalent at flow rates significantly below the design flow rate of the basin (often the maximum flow rate), or at tailwater levels significantly higher than the tailwater needed to create the hydraulic jump (i.e., the conjugate depth or sequent depth). In this condition, the high velocity jet along the floor rises off of the floor before the end of the basin, and this creates a counter-rotating eddy in the downstream part of the basin that leads to a stalling of flow at the floor. Rocks that are already in the basin collect and circulate in this zone, described by Zeigler as the *abrasion action area*, causing abrasion damage. The counter-rotating eddy in the downstream part of the basin also prevents rock from leaving the basin and can draw rock into the basin from the downstream channel. Narration of the film described how the flow conditions tend to hold rocks captive in this area, continually churning them against the floor and walls. With lower discharges the abrasion action area is located further upstream in the basin, and the abrasion action area moves downstream as the basin discharge is increased. With sufficient discharge, rocks can be flushed from the basin, but lower discharges may lead to that rock being drawn back into the basin. Zeigler's study of the Mason Dam stilling basin was only documented in the short film and in a draft report (Zeigler 1990), which also gave extensive background on the history of damage in the Mason Dam outlet works basin. This study considered the addition of a rock trap downstream from the end sill to prevent migration of rock into the basin, but did not consider any internal modifications to the basin. However, subsequent physical model studies (Hanna 2005) which are reviewed later in this report led to the development and installation of a flow deflector in the basin that successfully addressed the abrasion damage problem. The remainder of this literature review will summarize hydraulic model studies conducted to study flow deflectors for several Reclamation stilling basins.

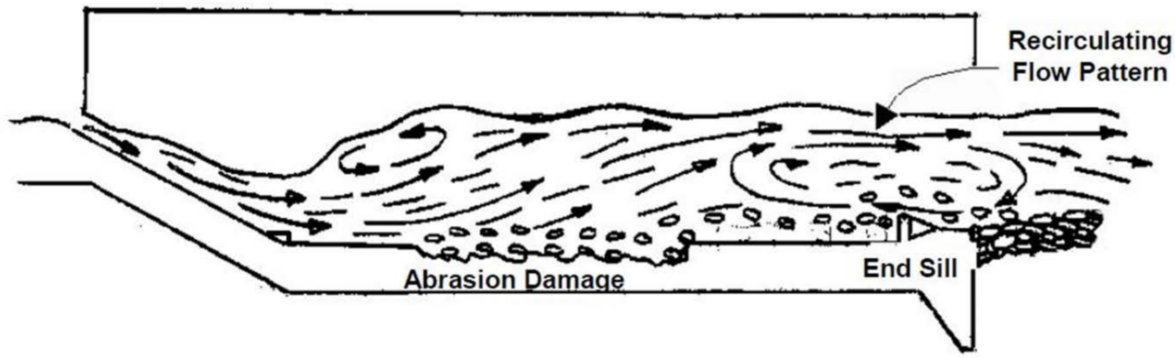

Figure 3. — Area of abrasion damage and the recirculating flow pattern produced over end sill during normal operations.

Taylor Draw Dam

The first hydraulic model study that considered structural features to address a stilling basin abrasion problem was for Taylor Draw Dam, a non-Reclamation facility located near Rangely, Colorado. Within the first 3 years of operation the concrete walls and floor of the outlet works chute and Type III stilling basin experienced significant damage. In 1987 the damage was repaired with silica fume concrete and a metal roof was added to prevent rocks from falling or being thrown into the basin. Subsequent underwater inspection in 1989 revealed significant new damage to the concrete surfaces. Engineers from the Colorado River Water Conservation District then contacted Reclamation to determine if similar damage had occurred in Reclamation stilling basins. These inquiries and subsequent discussions led to a physical model study.

A 1:10 scale physical hydraulic model of the Taylor Draw Dam outlet works stilling basin was tested in Reclamation's Hydraulics Laboratory to determine the cause of concrete damage and develop modifications to prevent future damage (Dodge 1992). The model showed that the flow exiting the outlet gate lifted off of the chute floor and concentrated to one side near the water surface. The concentrated surface flow produced return flow over the downstream basin sill. The separation of the outlet flow from the incoming chute floor was a more severe problem than the general separation of flow from the stilling basin floor seen by Zeigler in the Mason model. A vortex generated from a bifurcation upstream from the gate caused these flow conditions. The return flow brought rocks as large as 9 inches in diameter into the basin. The churning and tumbling rocks severely abraded the concrete, even across the toe of the chute at the upstream end of the basin (Figure 4; Resource Consultants, Inc. 1991).

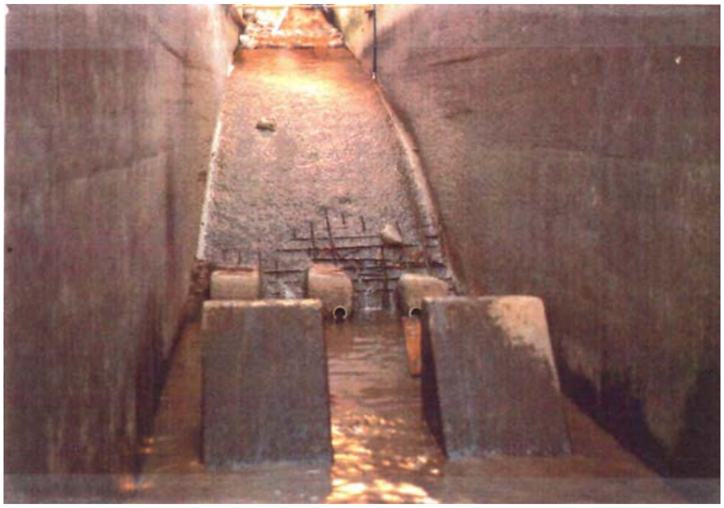

Figure 4. — Inspection photo from Taylor Draw Dam outlet works stilling basin, 1987.

The model study indicated that the poor flow conditions could be corrected by installing two flow deflectors, one over the parabolic chute near the gate (a chute deflector) and another near the downstream end of the basin (Figure 5). Pressures were measured on the model deflectors to determine structural loads. After the deflectors were installed in the prototype, field tests were performed and they verified that material was no longer being drawn into the basin (Dodge 1992). Hanna and Cohen (1997) reported that four years after installation, no further repairs to the basin had been needed.

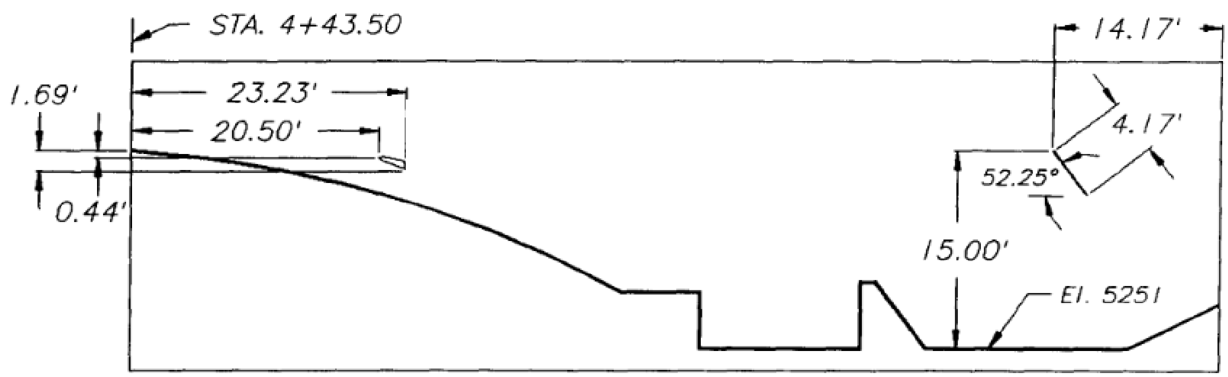

Figure 5. — Flow deflectors for Taylor Draw Dam outlet works stilling basin.

The use of dual deflectors and especially the chute deflector was unique and was driven by the unusually poor flow conditions entering the Taylor Draw basin. However, the basin flow deflector located near the end sill of the basin showed promise for addressing the general stilling basin abrasion problem described by Zeigler. The Taylor Draw study showed that the basin flow deflector could prevent back flow and material movement into a basin, but by itself would not ensure a self-cleaning basin. Rock entering a basin by other means could still cause considerable damage to concrete surfaces (Dodge et al. 1991).

Ridgway Dam

A 1994 underwater inspection of Ridgway Dam outlet works stilling basin (dam completed in 1987) revealed that the concrete floor was severely eroded, with reinforcing bars exposed (Mefford 1994). The cost of estimated repairs was between $200,000 and $1,000,000 (Hanna and Cohen 1997). The promising results of the Taylor Draw flow deflector installation led to studies of a possible deflector for the Ridgway basin.

A 1:10.5 scale physical hydraulic model of Ridgway Dam, a twin bay type II stilling basin, was constructed in 1995. The model was initially used to study the flow conditions and damage patterns, make recommendations regarding basin repair, and examine the potential for operational changes that might reduce further damage (Hanna 1996). Subsequently, the model was also used to study the potential benefits of adding a flow deflector above the end sill of the basin, similar to the downstream deflector added to the Taylor Draw basin (Hanna and Cohen 1997). The study considered the effects of deflector positioning and inclination on flow patterns over the basin end sill. The effectiveness of the deflector depended on the discharge and was sensitive to the deflector's vertical position relative to the dividing line between upstream and downstream velocities above the basin end sill, which changed over the operational flow range. In general, the study showed the deflector was most effective when it was inclined at an angle of 80 degrees from horizontal and positioned vertically to block the space between 38 percent (bottom edge of deflector) and 69 percent (top edge) of the average tailwater depth. When the variation of the tailwater levels (i.e. the operating range) was greater than 200 percent, a single deflector was not effective (Hanna and Cohen 1997). Despite the potential benefits demonstrated by the hydraulic model, no flow deflector has ever been installed at Ridgway Dam.

Mason Dam

The outlet works stilling basin at Mason Dam, completed in 1968, has a history of concrete surface abrasion and erosion damage, and as noted earlier was the subject of the first physical model study by Zeigler (1982). A cover was installed over the basin in 1977 to keep rocks from being thrown into the basin. Basin repairs were performed in 1994, but the 1999 underwater inspection again revealed severe concrete damage in the left bay with exposed rebar on the floor and at the base of the splitter wall. Due to the recurring damage to the basin concrete surfaces an additional physical model study was performed. A 1:7 scale model was constructed in Reclamation's Hydraulics Laboratory to aid the design of a flow deflector (Hanna, 2005). The studies focused on deflectors located over the end sill at a range of elevations and angles. The desired improved flow pattern with a flow deflector in place is shown in Figure 6. Following completion of the model study, a prototype deflector was installed at Mason Dam with the capability to adjust its elevation and angle, and a field evaluation was conducted in 2002 to verify the effectiveness of the design. A dive inspection in August 2004, after two seasons of operations with the deflector in place, found only a few stones in the basin and no indications of abrasion damage. A thin top layer of the new concrete was found flaking off but was attributed to freeze damage that occurred during concrete placement (Harris, 2005). A dive inspection in June 2005 also showed that the basin was in very good condition.

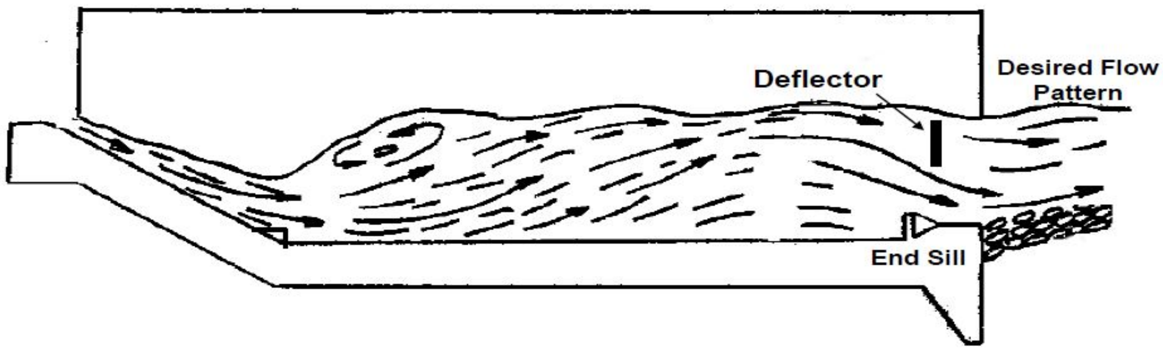

Figure 6. — Desired Flow Pattern with Flow Deflector in Place.

The 2012 Mason Dam underwater inspection (Hendrick 2012) revealed some signs of progressive aggregate relief—exposure and dislodgment of aggregate when surrounding cementitious material is eroded away—compared to the 2005 inspection. Areas of exposed rebar were also reported about 25 ft upstream from the end of the splitter wall, but the overall rates of erosion since the deflector installation were greatly reduced. Post-deflector dive inspections have consistently indicated that the basin is very clean with only a few small rocks present.

Choke Canyon Dam

In October 2004 a sectional model of the Choke Canyon Dam outlet works stilling basin was constructed at a 1:10 geometric scale in Reclamation's Hydraulics Laboratory to determine the optimal design for a flow deflector. For this model study, it was determined that one bay of the twin bay design was adequate to represent the stilling basin (Hanna 2010).

Initial observations of the flow showed that for operations above 40% gate opening, the high velocity flow would remain attached to the basin floor past the downstream end of the basin. Analysis of the design showed that the basin had been designed with a length optimized for flows smaller than those associated with maximum gate opening, and this was consistent with the historic range of typical operations. As a result, the 40% gate opening was chosen for the deflector design.

The Choke Canyon model study was unique compared to previous models because field measured velocities in the basin were available for comparison to the model. When velocities were compared, it was evident that even when incoming velocities were properly set to maintain equivalent Froude numbers for the model and prototype, the velocity profiles over the end sill did not match. The reverse-flow over the end sill was smaller in the model. This was attributed to differences in Reynolds numbers of the model and prototype. The Reynolds number is the ratio of inertial forces to viscous forces, while the Froude number is the ratio of inertial to gravitational forces and is normally used as the basis for modeling flows involving a free surface. Unfortunately, it is impossible to maintain equal Froude numbers and equal Reynolds numbers in a model that uses the same fluid as the prototype—water—and this can lead to overrepresentation of viscous losses in the model. To offset this scale effect, model discharge was increased above the values normally calculated from Froude scale similitude until velocity profiles matched those measured in the prototype (Hanna 2010).

An alternate explanation for the differences in model and prototype velocity profiles over the end sill of the basin is air entrainment scale effects. Flows in small-scale hydraulic models do not entrain as much air as prototype-scale flows because it also impossible to maintain equal Weber numbers in model and prototype—the ratio of inertial to surface tension forces. Observation of stilling basin models shows that the jet rising from the basin floor corresponds with the location of a buoyant plume of aerated flow, and this rising flow seems to drive the counter-rotating eddy that forms over the basin end sill. Reduced air entrainment in a model may reduce the intensity of this effect, and may also cause under prediction of the air bulking in the basin, which affects water surface profiles in the model. The potential for these scale effects is an important reason for obtaining field data, which may aid the accurate representation of flow conditions needed to achieve accurate placement of deflectors (Hanna 2010).

In addition to the 1:10 scale model, a second 1:6 scale model of the Choke Canyon Basin was used to study scale effects (Hanna 2011). To obtain better representation of the velocities over the end-sill, Hanna found that the model discharge for any given gate opening could be increased by an amount related to the model scale ratio and the percentage of the basin design flow discharge. It is uncertain whether determination of an effective deflector position is sensitive to accurate modeling of the magnitude of the end sill velocities, but it probably is sensitive to shifts in the elevation at which the velocity profiles crosses through zero (i.e., the dividing line between upstream- and downstream-directed flow), and this does also seem to differ between model and prototype.

In December of 2006 flow deflectors were installed in each of the twin bays of the Choke Canyon outlet works stilling basin. In February of 2007 field tests were conducted to verify the effectiveness of the flow deflector design. Divers installed a flow measurement device on the downstream face of the end sill. Overall, the deflector successfully modified the flow over the end sill to reduce the potential for materials to be drawn into the basin. However, a range of discharges was identified where the flow in the basin was relatively unstable, with some upstream surging. Instability of the hydraulic jump is not unusual for these types of stilling basins and although the average flow was still in the downstream direction over the end sill, such operating zones may not fully benefit from the deflector installation. Recommendations were made to avoid operations within this zone.

The 2011 underwater examination report stated the concrete floor of the stilling basin bays were clean and free from rock or sand deposits. This indicated that the deflector was functioning as designed and that the operations were no longer pulling material back into the basin. Additionally, the foundation/riprap contact at the downstream sill of the structure was about 18 inches lower than the sill, indicating material had not moved back upstream into this area since it was cleared during deflector installation (Hawkins, 2011).

Haystack Dam

The Haystack Dam outlet works stilling basin was selected for a study of Reclamation’s Type III stilling basins. The stilling basin and gate structure were modeled at a 1:6.5 geometric scale. To simplify the model, the horseshoe tunnel approaching the chute was shortened and the basin wingwalls were removed. In addition, the concrete apron downstream from the basin was replaced with riprap to more closely simulate typical Type III stilling basins (Hanna, 2010).

The velocity profiles measured in a vertical plane at the end of the basin were well defined and closely grouped throughout the full range of discharges tested. This regularity was attributed to the baffle blocks, a feature of standard type III stilling basin design, which act to lift the jet off the basin floor at a consistent distance upstream from the end of the basin. This produces a consistent velocity profile at the end of the stilling basin throughout the full operating range.

A comparison of the Haystack Dam stilling basin and the design guidelines for standard Type III basins in Engineering Monograph No. 25 showed that the basin was oversized in length by almost 10 ft. Following initial testing to develop a deflector position appropriate for the oversized basin (for potential installation in the prototype), the model was modified to a shorter basin length that more closely represented a standard Reclamation Type III stilling basin. To develop general design guidelines for deflectors in standard Reclamation Type III basins testing was performed using the modified model at the design discharge for the site. In general, the optimum deflector position in a Type III basin is farther upstream than in a Type II basin, and the only poor performance occurs when the deflector is positioned near the extreme downstream end of the basin (Hanna, 2010). Although the model studies were considered successful, no flow deflector was installed at Haystack Dam.

Fontenelle Dam

Another physical hydraulic model at a 1:16 scale was constructed in Reclamation's Hydraulics Laboratory to evaluate the hydraulic characteristics of the Fontenelle Dam river outlet works Type II stilling basin and to design a flow deflector or a series of flow deflector panels for mitigating abrasion damage (Hanna, 2007). The Fontenelle basin is the widest basin where a flow deflector has been considered, with a width of 62 ft. Stilling basins wider than about 25 ft present an additional challenge due to the loads applied to a deflector and the tendency of the incoming jet or hydraulic jump to attach to one side of the basin, thus creating non-uniform flow conditions at discharges less than the maximum design flow for the basin. In addition, the hydraulic jump will often oscillate from one side of the basin to the other, even when there are no changes in gate operations. The final optimal deflector design consisted of two stationary deflectors near the end sill, with vertical orientations, and staggered in longitudinal position. The upstream deflector was larger and positioned higher above the basin invert elevation than the downstream, lower deflector. With this arrangement, the model showed significantly improved flow conditions with velocities above the end sill directed downstream (Hanna, 2007). Despite the improved performance demonstrated in the model, the deflectors were never installed in the field.

Literature Review Summary

Physical model studies conducted in Reclamation's Hydraulics Laboratory have identified flow conditions that set up counter-rotating eddies over the end sills of stilling basins, causing entrainment of rock from downstream, entrapment of rock that has entered the basin by other routes, and abrasion damage to floors and walls. Flow deflectors were developed as a cost-effective remediation solution for this type of damage for several Type II and Type III stilling basins. Model study results were then used to develop standard guidelines for the design of flow deflectors for basins with widths of 25 feet or less. Field installations at Taylor Draw Dam, Mason Dam, and Choke Canyon Dam verified that flow deflectors were successful in reducing the amount of materials brought into the basin from downstream, thus reducing the damage to the basins. Underwater examination reports within the first 5 years of each of the installations reported positive performance for the flow deflectors with little to no new reported damage to the concrete in the basins (Hanna 2010).

Further generalization of the results from the many site-specific stilling basin studies led to the development of flow deflector design guidelines for precise placement and geometry of deflectors in type II and type III stilling basins with widths of 25 feet or less (Hanna 2015). To develop deflector designs, a velocity profile measurement is needed at the downstream end of the basin, either in the field or in a physical model study. Investigations thus far have shown that a staggered deflector design option may be the most practical solution for most type II stilling basins of standard design. Simplified design guidelines were also developed for a single oversized flow deflector which would not require measurements of velocity profile data at the downstream end of the basin. The oversized deflector guidelines were based on results from a limited study, so further research may be necessary to refine and optimize the guidelines (Hanna 2015).

Although the design guidelines developed thus far have focused on narrow basins, flow deflectors have been found to be effective for basins wider than 25 feet, but always require a physical model study due to the complexity of flow conditions associated with the wider basins.

Hanna (2011) attributed differences in model and prototype velocity profiles to Reynolds number differences between model and prototype (i.e., viscous scale effects). It is also plausible that the reason is Weber number differences (i.e., surface tension scale effects). Unfortunately, like many problems involving these two scale effects, it is difficult to isolate either effect, since the Reynolds and Weber numbers change in unison. In theory, one way to determine which effect is really the root cause of the issue is to operate models with heated or cooled water, since viscosity is very temperature dependent, while surface tension is not. This enables the Reynolds number to be varied while the Weber number is held almost constant. If model performance is seen to be affected by the temperature change, then the effect is related to the Reynolds number. If model performance is unaffected, then the differences that have been observed between model and prototype are probably related to the Weber number. In the case of a model stilling basin, to operate at a Reynolds number closer to the prototype, the water should be heated, which will reduce viscosity and viscous losses. Unfortunately, there are practical difficulties (and safety issues) in operating models with heated or cooled water. It might be more practical to test for Reynolds or Weber effects by operating with cooled water, even though that would push the model to a Reynolds-number condition that is farther from the prototype case. In the end, this question may be mostly academic; from a practical standpoint, the adjustment method proposed by Hanna (2011) does not depend on knowing the exact mechanism by which the scale effect occurs, so the adjustment procedure may be effective in either case. At this point, the body of experience is still very small, so applications should not rely solely on adjusted or unadjusted model results; when possible, prototype velocity profile measurements should be made to verify model results before a final deflector design is completed.

Distorted behavior of two-phase air-water flows is a common source of scale effects in hydraulic models. Pfister and Chanson (2014) stated that "Underestimation of air entrainment in free-surface flow in physical models may be minimized if lower threshold values of Weber and Reynolds numbers are respected." With both model study and field velocity data available for the Mason and Choke Canyon stilling basins, potential exists for a comparative analysis. A few preliminary comparisons suggest that large models (scale ratios in the 1:6 to 1:8 range, typical of most of the stilling basin deflector studies at Reclamation) probably suffer minimal scale effects at maximum flow, but may be significantly affected at low flow rates. Models smaller than 1:10 probably suffer aeration distortion for all flow rates, and are most severely affected at low flow rates.

Reclamation Stilling Basin Survey

Zeigler (1978) created an inventory of Reclamation stilling basins and studied the condition reports of these basins to identify the prevalence of abrasion damage problems. As part of the current study, a new inventory has been assembled to identify where abrasion damage exists or has existed and the current condition of Reclamation stilling basins. The focus has been kept primarily on outlet works basins with a width of 25 ft or less. The facilities that could potentially benefit from flow deflector installation were identified and a survey form was developed that could be sent to facility managers to determine the need and interest in flow deflectors for specific facilities.

Developing an updated inventory of Reclamation's stilling basins was conducted by accessing Underwater Dive Reports, Comprehensive Facility Reviews (CFR), Examination Reports, Annual Examination Reports, and O&M reports. The DSDams database was the primary source for reports that were obtained. Forty years prior to this current Reclamation type II and type III stilling basin inventory survey, Zeigler used similar sources, including Review of Maintenance Program reports (from both E&R Center and Regional level), underwater diver reports, travel reports, and correspondence. Because none of these information sources were primarily intended to meet the needs of this study, Zeigler found it challenging to extract and summarize the desired information. He ultimately settled upon a tabular presentation format and four degrees of abrasion problem as indicated by keywords for the presence of **Rocks** in the basin, **Abrasion** damage, **Exposed Rebars**, and basins that had been "**Repaired**". A similar approach was taken in the current study.

The current inventory and the condition of the stilling basins is not considered to be complete. In compiling this inventory, nearly all of the reports found were scanned or read in full, as simple keyword searches did not yield the type of information that was sought. While reading through various reports, the occasional reference was made to other reports that were not included in the DSDams database. The frequency of DSDams underwater examinations were in 6-year increments at best and often less frequent, and the age of the underwater examinations varied from the current year to decades old. Underwater examination visibility also varied greatly. Some basins were described as completely covered by organic materials, silt, sand, gravel, or rock layers and the condition of the concrete surfaces were determined by either touch or the visible concrete above the covering material. In addition, the thoroughness of the different reports varied depending upon the author, dive team, or region responsible for the examination documentation.

No attempt was made to find, read, or include dewatered basin examinations, but CFR (Comprehensive Facility Review) and Annual examinations were included. However, neither the CFR nor the Annual examinations were underwater examinations, so the condition of the underwater concrete was often assumed to be similar to the condition of concrete visible above the water surface.

A summary of the current inventory is provided in Appendix A, identifying those basins that have experienced different levels of problems related to abrasion (i.e., rock in basin, erosion visible, exposed rebar, repairs made, etc.). Appendix B gives additional detail gathered from dive reports and other inspection documents. Appendix C provides the survey questionnaire that could be sent to facility managers for those facilities that were identified as having damage and potential for improvement from the installation of a flow deflector.

Not including the two Reclamation facilities that have been modified with flow deflectors (Mason and Choke Canyon), a total of 89 stilling basins were included in the inventory, with the majority serving to dissipate energy from outlet works or combined spillway and outlet works flows. Rocks or sediment were reported in 83 percent of these, and abrasion damage was reported for 64 percent. Exposed rebar was present in 22 percent of the cases and 15 percent (13 basins) had undergone repairs.

A combination of subjective and objective criteria were applied to determine that 44 of the facilities listed in Appendix A were potentially good candidates for installation of flow deflectors. Criteria considered in the evaluation included:

- Type II or Type III basin serving an outlet works or combined outlet works (basins serving only a spillway were not included because many spillways pass large woody debris at times, which can be problematic for a deflector)
- Width of individual basin bays ≤ 30 ft (two 30-ft wide basins were included, but the remainder are ≤ 25 ft)
- Rocks in the basin and erosion damage reported, especially if there are also reports of exposed rebar or repairs in the past.

Conclusions

A thorough review was conducted of the work that has taken place during the past 40 years to understand the problem of stilling basin abrasion and develop site-specific flow deflector designs to improve the flow conditions that lead to abrasion damage. Three specific basins (Taylor Draw Dam, Mason Dam, and Choke Canyon Dam) have been equipped with flow deflectors, and each installation has successfully led to significant reductions in damage rates and costly repairs. From the site-specific model studies and field experience, generalized design guidance has been developed for flow deflectors that can provide a cost-effective solution to abrasion damage problems in Reclamation type II and type III stilling basins.

A newly compiled inventory of Reclamation type II and type III stilling basins identified 44 facilities that could potentially benefit from flow deflector installation, based on basin size (widths ≤ 25 ft) and current condition of the concrete surfaces. Managers of these facilities should be contacted with the survey, included in Appendix C, to gauge their interest in pursuing the development of a flow deflector design.

Scale effects related to viscous hydraulic friction losses or two-phase air-water flows have had some effect on the physical hydraulic model results, but the exact mechanism by which the scale effects occur is still uncertain. At this time it is advisable for the design of a deflector to rely on a combination of small-scale physical model testing and prototype velocity profile measurements in the field. Further research could help to determine the root cause of the scale effects and validate methods for adjusting physical model results to overcome them.

Flow deflectors can provide a solution to stilling basin abrasion problems in basins wider than 25 ft, but the complexity of flows and magnitude of forces in such wide basins makes it imperative that physical models be used for development of an optimized and fully effective design. The potential exists for further research to develop new mitigation devices for wider stilling basins.

Recommendations

- Contact managers of the 44 facilities identified in Appendix A to determine their interest in reducing stilling basin abrasion through flow deflector design and installation.
- Continue to perform combined field studies and lab-scale physical model studies when developing stilling basin deflector designs, and used collected data to evaluate proposed methods of adjusting for scale effects in physical models. Consider research studies to solidify the understanding of the processes causing scale effects and investigate better methods for avoiding or accounting for them.
- Consider future research studies to develop an oversized single flow deflector design that can be applied to multiple facilities, eliminating the need for site specific physical hydraulic model studies and field velocity evaluations. This effort would likely include physical model testing in Reclamation’s Hydraulics Laboratory over a range of operating conditions and basin geometries to extend initial efforts by Hanna (2015).

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Appendix A - Reclamation Stilling Basin Abrasion Damage Inventory

Typical Bureau of Reclamation stilling basin types:

- Type I – simple hydraulic jump on apron…no chute blocks, deflector blocks or end sill
- Type II – chute blocks and end sill (probably with dentates)
- Type III – similar to Type II, but also has mid-basin baffle blocks
- Type IV – chute blocks and end sill, for Fr = 2.5 to 4.5
- Type V – sloping apron (usually has end sill, typically no chute blocks)

Dam Name	Facility Type S=spillway OW=outlet works	Rocks	Abrasion	Exposed Rebars	Repaired	Basin Type	Basin Width (ft)	Contact for Interest
Arbuckle Dam	OW	X	X		X	Type II	20’	YES
A.V. Watkins	OW	X	X			Type II	13’	YES
Bull Lake Dam	S	X	X			Type II	100’	NO
Bull Lake Dam	OW	X	X			Type II	30’	YES
Bully Creek Dam	OW	X	X			Type II	8’	YES
Bully Creek Dam	Canal OW	X	X	X		Type II	15’	YES
Causey Dam	S	X	X	X		Type II	25’	NO
Causey Dam	OW	X	X			Type II like	18‘(2@9'2" splitter wall)	YES
Cheney Dam	S	X	X	X		Type III	25’	NO
Cheney Dam	OW	X	X			Type III	25’	YES
Choke Canyon Dam	OW					Type II	21’ (2@10' splitter wall)	Follow up on installed deflector
Contra Loma Dam	S	X					15’	NO
Contra Loma Dam	OW	Sediment					18’ (2@9' splitter wall)	NO
Crane Prairie Dam	OW	X				Type II like	20’	NO
Crawford Dam	S	Sediment	Y			Type II	25’	NO
Crawford Dam	OW					Type II	15’	NO
Crescent Lake Dam	OW	X	Minor			Type II	20’	NO
Emigrant Dam	OW	X	X		2000	Type II	16.5'	YES
Emigrant Dam East Lateral Canal Stilling Basin		X	X	X				YES

Dam Name	Facility Type S=spillway OW=outlet works	Rocks	Abrasion	Exposed Rebars	Repaired	Basin Type	Basin Width (ft)	Contact for Interest
Enders Dam	OW	1997 Dive report	X	1976 Dive report		Type V	30’	YES
Foss Dam	OW					Type III	25’	NO
Glen Elder Dam	OW	X	X				25’(2@12' splitter wall)	YES
Grassy Lake Dam	S					Type II	20’	NO
Haystack Dam	OW					Type III		NO
Heart Butte Dam	S	X				Type II	35’	NO
Heron Dam	OW	X					25’	NO
Howard Prairie Dam	S	X				Type II	25’	NO
Hyrum Dam	S	X	X				16’	NO
Jackson Gulch Dam	OW	X	X	X	X	Type II	12’	YES
Joes Valley Dam	S	X	X			Type II	25’	NO
Joes Valley Dam	OW	X	X			Type II	15’	YES
Kachess Dam	OW	X	X			Type II	22’	YES
Keechelus Dam	OW	X	X	X		Type II	18’	YES
Keene Creek Dam	S	silt & rock	X			Type II	16’	NO
Little Panoche Detention Dam	S	sediment				Type II	18’	NO
Little Panoche Detention Dam	OW	silt & rock				Type II	30’	NO
Little Wood River Dam	OW						10’	NO
Los Banos Creek Detention Dam	OW	X	X			Type II	20’	YES
Lost Creek Dam	OW	gravel/ cobble bar	X			Type II	15’	YES
Mann Creek Dam	OW	gravel/ cobble bar	X			Type II	12’	YES
Mason Dam	OW					Type II	20’	Follow up on installed deflector
McPhee Dam	OW						30’	NO
Meeks Cabin Dam	OW	X	X	X		Type II	20’	YES
Merritt Dam	OW	X	X	X	1976	Type V	18' (2@9' splitter wall)	YES

Dam Name	Facility Type S=spillway OW=outlet works	Rocks	Abrasion	Exposed Rebars	Repaired	Basin Type	Basin Width (ft)	Contact for Interest
Morrow Point Dam	S	X	X	X				NO
Morrow Point Dam	OW	X	X	X				YES
Newton Dam	S	sediment	X			Type II	20’	NO
Newton Dam	OW	X				Type II	8’	YES
Ochoco Dam	OW	X	X	X			8'	YES
Pactola Dam	OW	X	X	X		Type V	20’	YES
Palmetto Bend Dam	OW						20’	NO
Pinto Dam	OW						25’	NO
Prosser Creek Dam	OW	X	X			Type II	20’	YES
Prosser Creek Dam	S	X	X			Type II	25’	NO
Red Fleet Dam	OW	X	X				20’	YES
Red Willow Dam	S	X					30’	NO
Red Willow Dam	OW	X	X				20’	YES
Ridges Basin Dam	OW					Type IV	20’	NO
Ridgway Dam	S	sediment & woody debris					38-40’	NO
Ridgway Dam	OW	X	X		1998	Type II	28’(2@14' splitter wall)	YES
Rifle Gap Dam	OW	sediment & rock					22’	NO
Ruedi Dam	S	X				Type II	30’	NO
Ruedi Dam	OW	X	X		X	Type II	25’	YES
Scofield Dam	OW	X	X	X		Type II	10’	YES
Scoggins Dam	S						40'	NO
Scoggins Dam	OW						20'	NO
Seminoe Dam	OW	X					30’	NO
Sherman Dam	S	fines to boulders				Type II	15’	NO
Sherman Dam	OW	X	X			Type V	22’(2@10’ splitter wall)	YES
Silver Jack Dam	OW	X	X		X		16’ (2@8' splitter wall)	YES
Spring Creek Debris Dam	S	X	X				25’	NO
Stampede Dam	S	X	X			Type II	20’	NO

Dam Name	Facility Type S=spillway OW=outlet works	Rocks	Abrasion	Exposed Rebars	Repaired	Basin Type	Basin Width (ft)	Contact for Interest
Stampede Dam	OW	X	X	X		Type II	28'6" (2@9'11 splitter wall)	YES
Starvation Dam	OW	X	X			Type II	20	YES
Stateline Dam	OW	X	X	X		Type II	11'	YES
Steinaker Dam	Combined S&OW						11'	NO
Stony Gorge Dam	OW						10'	NO
Sugar Loaf Dam	OW	X	X	X	2012	Type II	24'(2@12' splitter wall)	YES
Sugar Loaf Dam	S	X				Type II	25'	NO
Tiber Dam	OW	X	X			Type II	25'	YES
Tiber Dam	OW	X	X		X	Type III	24'	YES
Twin Lakes Dam	S						14'	NO
Twin Lakes Dam	OW	X	X				28' (2@14' splitter wall)	YES
Vega Dam	S	gravel	X			Type II	25'	NO
Vega Dam	OW	X	X			Type II	15'	YES
Virginia Smith Dam	S	X			X		20'	NO
Virginia Smith Dam	OW	X	X		2000		22'(2@10' splitter wall)	YES
Wanship Dam	OW	gravel bar	X	X	X	Type III	21'	YES
Wasco Dam	OW					Type III		NO
Wickiup Dam	OW	X	X	X	2008	Type II	30' (2@15' splitter wall)	YES
Willow Creek Dam MT	OW	X	X	X			25'	YES

Appendix B - Dive Reports and Inspection Notes

This table includes facilities listed in Reclamation's inventory of dams at https://www.usbr.gov/projects/facilities.php?type=Dam. Dive reports, Annual Exam reports and Comprehensive Facility Review reports were consulted for information about the condition of spillway and outlet works stilling basins. The following facilities were excluded from the table below because although they are listed in Reclamation's inventory of dams, there was no stilling basin information available, or they do not have a stilling basin of a type that is relevant to this study:

American Falls Dam, Anchor Dam, Anderson Ranch Dam, Angostura Diversion Dam, B F Sisk Dam, Belle Fourche Dam, Blue Mesa Dam, Brantley Dam, Buckhorn Dam, Buffalo Bill Dam, C.C. Cragin, Canyon Ferry Dam, Carpinteria Dam, Carter Lake Dam, Cascade Dam, Cedar Bluff Dam, Cle Elum Dam, Clear Creek Dam, Clear Lake Dam, Conconully Dam, Corbett Diversion Dam, Deer Flat East Dike Dam, Deer Flat Lower Embankment, Deer Flat Middle Embankment, Deer Flat Upper Embankment, Deerfield Dam, Dickinson Dam, Dille Diversion Dam, Dixon Canyon Dam, Dry Falls Dam, East Canyon Dam, East Park Dam, Fish Lake Dam, Flaming Gorge Dam, Flatiron Afterbay Dam, Folsom Dam, Fontenelle Dam, Fort Cobb Dam, Foss Dam, Fresno Dam, Friant Dam, Fryingpan Diversion Dam, Gerber Dam, Gibson Dam, Glen Anne Dam, Glen Canyon Dam, Glendo Dam, Granby Dam, Grand Coulee Dam, Helena Valley Dam, Hoover Dam, Horseshoe Dam, Hubbard Dam, Hungry Horse Dam, Huntington North Dam, Hyrum Dam, Jackson Lake Dam, Jordanelle Dam, Kent Diversion Dam, Lahontan Dam, Lake Alice No 1 Dam, Lake Alice No 1 and 1 Half Dam, Lake Alice No 2 Dam, Lake Sherburne Dam, Lake Tahoe Dam, Lauro Dam, Lemon Dam, Lower Two Medicine Dam, Martinez Dam, Marys Lake Dike Dam, McGee Creek Dam, McKay Dam, Midview Dam, Moon Lake Dam, Mormon Island Auxiliary Dam, Mt. Elbert Forebay Dam, Nambe Falls Dam, Nelson Dam, New Melones Dam, New Waddell Dam, Nimbus Dam, Norman Dam, North Dam, Ortega Dam, Parker Dam, Pishkun Dikes, Pole Hill Afterbay Dam, Pueblo Dam, Putah Diversion Dam, Ralston Dam, Red Bluff Diversion Dam, Reservoir A Dam, Salmon Lake Dam, San Justo Dam, Satanka Dike Dam, Senator Wash Dam, Shasta Dam, Soldier Canyon Dam, Spring Canyon Dam, St. Mary Diversion Dam, Stewart Mountain Dam, Yellowtail Afterbay Dam.

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
Agate Dam	12/5/2014	Overall, the combined spillway and outlet works stilling basin is in very good condition and remained largely unchanged from the previous inspection. The rock accumulation in the basin may increase over time if visitors continue to throw/roll debris into the basin. At this time any damage that may have been caused by debris is minimal.
Agency Valley Dam	2/24/2011	600 cu yard on material silt and 2" rounded rock on stilling basin (4.5 to 5ft deep) not a great candidate for flow deflectors
Alcova Dam	2/26/2015	The dive report identifies locations requiring repairs on the basin walls. The previous concrete repairs to the stilling basin floor showed no signs of distress.
Altus Dam	10/12/2011	Spillway stilling basin good condition, surface relief of concrete floor was less than 1/4".
Angostura Dam	2/7/2012	Spillway stilling basin in excellent condition. Concrete surfaces smooth and sound, with no cracking or spalling. There was rock and gravel downstream of the dentates but was not seen as a concern.
Anita Dam		The 2007 Comprehensive Review Examination Report 2006-2-D Repair or replace the spillway. Vegetation was noted to be removed from the stilling basin (2003-2-A). No mention of concrete damaged of the basin was made.

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
Arbuckle Dam	1/19/2016	The river outlet works stilling basin has experienced some additional erosion since 2009, and possible active ball milling with concrete floor relief approaching up to 1.5-inch, particularly near the chute blocks. No reinforcing bars were observed in the eroded concrete floor. It appears that all the rock debris (noted in 2009 on the right side of the spillway stilling basin), has been removed due to the large flood event in 2015. The spillway stilling basin floor showed a small amount of surface roughness near the slab to wall interface that smoothed out toward the centerline of the basin. The extended duration of operation of the spillway along with the operation of the river outlet works may have contributed to the increased concrete relief in the river outlet works stilling basin due to differential flow rates. The assumed different flows rates in the basins may have allowed for rocks or debris to be pulled into the river outlet works stilling basin and caused a circular or rotating pattern of the debris on the concrete. It would be recommended, when possible, to have matching flows through both stilling basins after taking into account any and all dam safety needs first and foremost. When operating the river outlet works independently from the spillway, or after a long period of use, it is recommended that the outlet works be opened to a greater rate than would be expected for sustained operation for a small duration of time to "flush" rocks or other debris from within the stilling basin.
Arrowrock Dam	5/1/2001	Stilling basin not applicable for Flow Deflectors (too wide). Damage exists on toe of downstream face of dam.
A.R. Bowman Dam	2/14/2006	An estimated total of 58 cubic yards of rock material was noted during this examination. This is approximately 3 yd^3 more than what was noted in the 2003 examination, with most of the increase occurring just upstream of dentates Nos. 2 and 3. Measurements of the erosional monitoring pins showed no significant recent erosion when compared to the previous measurements. There was a slight increase, approximately 3 yd^3, in the amount of rock debris in the basin. Given the location of the new rock debris, it may be possible that the rock is being pulled hydraulically into the basin.
A.V. Watkins Dam	12/5/2015	The stilling basin was in satisfactory condition with little to no debris build up. The only notable concern was the middle chute block which has significant spalling. It should be repaired when possible.
Avalon Dam	9/6/2011	No dive reports addressing stilling basin.
Bartlett Dam		Stilling basin not appropriate for flow deflector.
Big Sandy Dam	4/22/2013	There was no damage found anywhere in the stilling basin. There was angular rock in the basin up to 18 inches.
Boca Dam	1/19/2012	The outlet works stilling basin was in good condition. The 2007 repair to the undercutting on the right end wall appears to be in good condition. No problems associated with this structure were noted. The spillway stilling basin was not examined. The basin had been drained and repaired in 2009, and no flows had been run through the basin since the repair.
Bonny Dam	11/1/2010	Spillway has never spilled. The sediment accumulation appeared to have increased since the inspection in 2000. The exposed concrete sections of the chute, chute blocks, dentates, and side walls were all found to be in good condition. A number of angular rocks, similar to the surrounding riprap material, were found in the basin along the side

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
		walls. This indicates no ball milling has occurred. However, it's possible more rocks and other debris are buried in the sediment accumulation.
Box Butte Dam	2016 CR report	No mention of adverse condition of spillway stilling basin.
Boysen Dam	8/18/2017	The spillway and outlet works stilling basins are subjected to inconsistent flow regimes and recirculating flows due to the proximity with one another and also the discharge flows from the two turbines.
Bradbury Dam	9/26/2013	The spillway stilling basin was in excellent shape; all chute block under drains were clean with no flow noted. All concrete relief was less than 1/2-inch. No wall or floor joint offsets were noted. All chute blocks and dentates were in excellent condition.
Bull Lake Dam	12/30/2010	Outlet works stilling basin had a damaged dentate (3rd from right side) that appeared to be from ball milling. Stilling basin had less than 12 4-inch diameter sized rocks in basin. The floor of the basin showed signs of abrasion damage, generally between 1 and 1-1/2 inches in depth.
Bully Creek Dam	6/22/2017	As noted in the 2008 underwater inspection report, both the outlet works stilling basin and the spillway stilling basin contain significant amounts of rock accumulation. An increase of approximately 10 yd^3 of material is present in the spillway stilling basin, while the material in the outlet works stilling basin remains relatively unchanged. The exposed areas of concrete in both basins still appear to be in good condition. The canal outlet works stilling basin has concrete erosion with exposed reinforcing steel.
Bumping Lake Dam		No underwater inspections of outlet works stilling basin found. 246-foot long concrete lined discharge channel, but no mention of stilling basin.
Caballo Dam	No dive report found containing information regarding stilling basins.	In the Comprehensive Review Examination Report it reads "The exposed portions of the concrete of the outlet works discharge pipe, discharge chute, and stilling basin are in satisfactory condition with no signs of significant cracking, spalling, damage, deterioration, or movement"
Casitas Dam	7/9/2010	Stilling basin was covered with 9 feet of fine sediments.
Causey Dam	3/25/2008	In the spillway stilling basin the rock material bar downstream of the chute blocks contained approximately 25yd^3, an increase of 5 yd^3 from the 2001 estimate. The accumulation of woody debris and rock debris at the chute blocks was approximately 10 yd^3 of material, with another 5 to 8 yd^3 of rock material on the sloping surface above the chute blocks. The two exposed rebars on the top surface of chute block 1 were unchanged from the 2001 inspection. The smooth floor indicates that the rock is not moving that would cause additional erosion on the floor. The outlet works stilling basin exhibited areas of abrasion damage, none of which was considered excessive. Total debris accumulation in the outlet works chute was less than 1 yd^3.
Cheney Dam	6/4/2014	The river outlet works stilling basin was much cleaner than the spillway basin, with sediment and mussel shell fragments ranging from 1- to 6-inches thick encountered on the floor of the basin. Some riprap was observed along the right wall between the baffle blocks and baffle piers. Up to 2 feet of sediment was deposited near the end sill and

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
		riprap bedding. Concrete damage on the left wall near the baffle piers should be monitored periodically. Approximately 4 to 5 feet of sediment was found in the bottom of the spillway stilling basin. Boulder and cobble sized rock was noted on top of sediment in the area of the chute blocks. Chipping was noted on some of the concrete baffle blocks.
Choke Canyon Dam	10/26/2011	The concrete floor of the stilling basin bays was clean and free from rock or sand deposits. This was taken as an indication that the downstream deflector plates were functioning as designed and that the operations were no longer pulling material back into the structure. Additionally, the foundation/riprap contact at the downstream sill of the structure was about 18 inches lower than the sill, indicating material had not moved back upstream into this area since it was cleared during deflector installation in the early 2000's.
Clark Canyon Dam	12/18/2017	The spillway stilling basin floor immediately downstream of the chute blocks has experienced between ½ inch and 1 inch of concrete relief. No undercutting was observed or felt at the downstream end of the spillway stilling basin. The dentates were clear and in good condition with well-defined corners and edges. Concrete relief was between 1/8-inch and ¼-inch near the dentates. The dentates were clear of any rock or heavy organic debris buildup. In the outlet works stilling basin, the 5-yd3 sand and gravel bar, located near the downstream edge of the chute blocks in the 2008 dive report, appears to have been flushed out of the basin. The area of exposed rebar and concrete erosion appears to be almost identical to what was reported during the 2008 examination. The chute blocks were in good condition with some broken edges and slight rounding of the outside corners of the concrete. All the drains were clear and flowing a small amount of clear, cold water. The concrete surface of the dentates were smooth and in good condition. The edges of some of the dentates were reported to be slightly rounded.
Cold Springs Dam	3/9/2018	No information regarding condition of 5- by 9-ft concrete lined tailrace conduit 142-ft in length.
Como Dam	2018 Annual Site Inspection Report	Outlet works stilling basin is concrete buttered rip rap lined.
Contra Loma Dam	8/19/2013	The walls and floors along with the chute blocks and dentates of the outlet works stilling basin were in good condition. Fine sediments from 6 to 18 inches deep were in the right bay while the left bay had a thin layer of sediments suggesting that the right bay had been used more to control outlet works flows. The entire spillway stilling basin was covered with 2 to 18-inch diameter angular rock. Water marks and organic growth suggested that the spillway had not been recently used. The rock most likely was not pulled into the stilling basin by recirculating flows.
Crane Prairie Dam	10/26/2012	YES, sub rounded rock accumulation downstream of the end sill and between the dentates and end sill suggests rock may be pulled into the basin due to recirculating flows.
Crawford Dam	2/23/2017	The outlet works stilling basin and the spillway stilling basin contain approximately 190 cubic yards of fine-grained sediments and a minor amount of angular rock. The rock could have been thrown into the

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
		basin over time and does not appear to be causing any damage to the concrete surfaces.
Crescent Lake Dam	9/14/2001	The concrete that was exposed in the stilling basin showed only minor damage and wear; however a significant area of the stilling basin floor was covered with rock debris, which may be masking more severe concrete damage...if higher than normal flows are experienced, substantial damage could occur over a short time.
Crystal Dam	11/23/2009	Spillway discharges into an unlined plunge pool.
Currant Creek Dam	5/22/2013	Although sub-rounded material was observed in the outlet works stilling basin, no sign of erosion was detected. The outlet works stilling basin and outlet works bypass stilling basin are both in good condition. The spillway stilling basin was not examined due to not releasing any water since the last examination in 2006. *Note the 2006 diver report inspected the outlet works intake only. (The 2002 dive report indicated that the spillway appeared to be in good condition. No evidence of deterioration or damage was located during the underwater inspection.
Davis Creek Dam	No dive report found.	2012 Comprehensive Review Examination Report indicated the stilling basin was dewatered and fourteen holes were drilled in the basin. Several of these holes were located to intercept the drains below the structure. Several of the holes drilled into the foundation indicated voids below the base of the concrete. No mention of abrasion damage in concrete surfaces of stilling basin concrete.
Davis Dam	7/17/2014	All portions of the dentates that were inspected were in satisfactory condition with no significant deterioration or spalling of the concrete. Downstream of Spillway Gate #3 there was large amount of debris between the sets of dentates (Photo 16). The nearly 4-foot-high debris pile was mostly made up of large rocks and gravels (Photos 17 and 18). There appeared to be a channel cut out of the debris pile directly downstream of the east radial gate. The operators stated that the gate had never been operated, to their knowledge, so it was unlikely that flows from the gate cleared the debris. But downstream of the radial gate there was no debris pile and directly adjacent to it 5 Inaccessible Feature Review Davis Dam Draft Tubes, Trashracks, Spillway Gates, Radial Gates and Stilling Basin Parker-Davis Project the pile was at its highest. The pile extended the entire length of the stilling basin between the two sets of dentates and tapered down to the west towards Gate #2. The pile then extended downstream of the dentates.
Deadwood Dam	4/11/2007	All areas of the combined stilling basin were in good condition. However, the two areas of undercutting at the left bridge pier abutment are progressing in size. While this does not pose an immediate threat to the bridge structure, it is recommended that these erosional areas be filled with concrete material as soon as practical.
Deaver Dam		Not a high head dam. 2000 Annual Exam report states spillway and outlet works stilling basins are both in satisfactory condition.
Deer Creek Dam	9/5/2012	The accumulation of approximately 200 cubic yards of cobbles and boulders located in the spillway stilling basin and covering much of the chute blocks and dentates during the 2000 inspection was largely gone. All of the chute blocks and dentates could be easily found and examined closely during this inspection. Chute block drains were found

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
		to be clear and noted to be in good condition. Both chute blocks and dentates were completely covered with a thin layer of organic growth. Underneath this organic growth on the dentates, calcium appeared to have leached out of the concrete and reacted with carbonate ions in the water to form a soft uniform layer of white chalk (calcium carbonate). However, the concrete further underneath still appeared to be in good condition. The floor of the basin was also noted to be smooth and in good condition.
Echo Dam	4/24/2012	Not a type II or III stilling basin.
Eden Dam	No dive report found.	2012 Comprehensive Review Examination Report states the stilling basin is inspected by operations personnel at the end of each irrigation season.
El Vado Dam	1/30/2001	Not type II or type III basin, plunge pool
Elephant Butte Dam	No dive report about basin	2011 Comprehensive Review Examination Report states "The combined outlet works/ spillway downstream discharge channel is in satisfactory condition with no large vegetation and/or debris which could block flows.
Emigrant Dam	9/27/2013	The patch completed in late 2000 is holding strong with 1/2 inch to 1/4 inch concrete relief observed throughout the basin floor. One-inch concrete relief was observed on the dentates and chute blocks. The comers were rounded, but no damage was observed. A rock debris bar is located around the chute blocks, and also upstream of the dentates. The rest of the rock material in the basin is scattered sporadically. The rock material consists of 14-inch and minus sub-angular material. Approximately 1/8 cubic yards of material is in the stilling basin.
Enders Dam	12/15/2011	The outlet works stilling basin appeared to be in satisfactory condition, with no exposed rebar or deterioration of concrete noted. The floor of the basin was observed to have some minor relief, but no cause for concern.
Four Mile Lake	9/21/2005 O&M Exam	Fourmile Lake Dam is not owned by the Federal Government. Reclamation became involved in the dam during the 1950's modifications. Later, the dam was included in the 1984 amendment to the Reclamation Safety of Dams Act of 1978. Section 12 of the 1984 Amendment (Public Law 98-404 August 28,1984) is as follows "Included within the scope of this Act are Fish Lake, Four Mile, Ochoco, Savage Rapids Diversion, and Warm Spring Dams, Oregon; Como Dam, Montana; Little Wood River Dam, Idaho; and related facilities, which have been made a part of a Federal reclamation project by previous Acts of Congress...."
French Canyon Dam	No dive report found.	The 2013 comprehensive Review Examination Report indicates the visible portions of the stilling basin for the concrete-lined spillway channel is in satisfactory condition, with no damage or defects to the concrete. According to Area Office personnel, the stilling basin was last dewatered and inspected in 2007; no damage to the basin has been reported.
Fruitgrowers Dam	3/3/2016	No mention of stilling basin in dive report. In the 2016 Comprehensive Facility Examination report notes that the spillway does not have a stilling basin. On November 23, 2010, the outlet works stilling chamber was examined [5]. Two areas of spalling concrete were observed in the stilling chamber, there was grout on the concrete chamber floor, and

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
		the access ladder and drain metal work was corroded. According to the 2010 travel report, the stilling chamber is in fair condition, is functioning properly, and is showing signs of aging. The 2010 travel report states that the spalled concrete in the stilling chamber should be patched; however, no operation and maintenance (O&M) recommendation was made. The outlet works stilling chamber was inspected during this March 29, 2016 CR civil examination. The condition of the chamber was observed to be similar to that noted during the 2010 inspection. Minor spalling of the stilling chamber walls and grout from the 2004 repairs were observed. The slide gate for the chamber drain is severely rusted and corroded (photo CE-83). The access ladder to the chamber is also rusted.
Funks Dam	1/30/2014	The stilling basin concrete is in excellent condition. The accumulated material does not appear to affect the structural integrity of the basin. The drains were not able to be observed due to the material accumulation.
Glen Elder Dam	6/19/2006	Overall, the outlet works stilling basin structure appeared to be in satisfactory condition. The only deterioration found was in the basin floor in the area immediately upstream of the downstream end of the central splitter wall, where the maximum surface relief was 1/2 inch. A minor quantity of angular and sub-angular rocks was found in both bays. These rocks appeared to be of the same material type and size as those used for river channel protection downstream of the basin. The floor contact with the central splitter and outside walls was in satisfactory condition. The conditions of the basin floor appeared to be similar to what was reported in the last underwater inspection. All four chute blocks were in good condition. All four dentates were in satisfactory condition. The downstream contact with the river channel was tight and no undercutting of the end sill was found. The counterforts along the outside wall were also in satisfactory condition.
Grassy Lake Dam	Annual Exam Report 8/31/2018	It was discussed during the inspection the possibility of dewatering and inspecting the stilling basin next year as it has been over 10 years since it has been accomplished.
Gray Reef Dam	11/28/1984	The spillway stilling basin was found to be in excellent condition. No concrete damage or buildup of rock, debris, and silt was evident.
Green Mountain Dam	7/29/2016	2016 Comprehensive Facility Examination Report makes no mention of outlet works stilling basin.
Guernsey Dam	11/28/1984	No mention of stilling basins for the spillways in the 2011 Comprehensive Facility Examination Report.
Haystack Dam	7/21/2011	The overall condition of the outlet works stilling basin was good. No rocks, gravel deposits, or exposed rebar were noted in basin.
Heart Butte Dam		The 2011 Comprehensive Facility Examination Report states "during this examination, the visible (above-water) portion of the chute and stilling basin concrete was in satisfactory condition, with only minor old cracking and spalling, and no significant deflections or deformations." It was observed that "Discharge in the chute and stilling basin appears to be smooth with no significant turbulence or obstructions to flow." Similar to a type II stilling basin. In October 2004, DKAO personnel examined the stilling basin after it was dewatered. The resulting inspection report concludes that the stilling basin is in generally satisfactory condition, with only minor concrete

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
		deterioration at the contraction joints. The chute blocks and dentates were reported to have no significant damage.
Heron Dam	4/3/2007	The outlet stilling basin appears to be in similar condition as that reported in October 2000. Only minor concrete scour (maximum about 3/4-inch deep) was present near the center of the basin. The energy dissipating chute blocks and dentates were in good condition with only minor chipping on a few edges. The basin was free of rock debris, except for about 1/4 yd^3 at the downstream base of the chute blocks.
Horse Mesa Dam	No dive report found	Not a type II or type III stilling basin.
Horsetooth Dam		2000 Annual Inspection Report shows the outlet works stilling basin being in satisfactory condition. No mention of any issues with outlet works stilling basin in 2016 Comprehensive Review.
Howard Prairie Dam	9/30/2013	The chute blocks and dentates within the spillway stilling basin were in good condition, with no concrete damage noted. The drains in the chute blocks were covered with rock debris. The floor of the basin exhibited signs of minor erosion, with 1/4 inch of relief throughout most of the basin. Approximately 20 cubic yards of gravels, cobbles, and boulders up to 13 inches in diameter were found within the basin. The lack of concrete damage within the basin indicates that removal of this debris is not a high priority at this time.
Hyatt Dam		The conduit discharge portal is in generally satisfactory condition; previously-observed spalling does not appear to have changed since previous examinations. The discharge channel immediately downstream from the discharge portal, upstream from the ramp flume is clear and unobstructed. The ramp flume is in satisfactory condition, with no large cracks, spalls, or other major damage or deterioration to the concrete observed. (2015 CR Report)
Island Park Dam	8/23/2017	Spillway and outlet works discharge channel but no stilling basin mentioned in the 2017 Comprehensive Facility Examination Report.
Jackson Gulch Dam	1/27/2011	The overall condition of the outlet works stilling basin was very good. The concrete repair in the right bay is still holding up very well. The exposed aggregate with maximum I-inch relief around the chute blocks and the chute block floor area was uniform, with a few areas of localized erosion. The one area along the wall with the exposed rebar is currently not a problem, but needs to be monitored for signs of accelerated erosion.
Jamestown Dam	10/20/2009 Stilling Basin Inspection Examination Report	Minor spalling on the concrete floor with a maximum depth of 1-3/4" in the spillway stilling basin. Overall the condition of the outlet works stilling basin was in good condition.
Joes Valley Dam	10/13/2015	Both the outlet works stilling basin and spillway stilling basin were in satisfactory condition. The outlet works stilling basin contained 2 yards of rounded rock and metal. The spillway stilling basin was covered with sediment 5 to 14 inches deep.
Kachess Dam	5/29/2012	There are areas of erosion and undercutting in the outlet works stilling basin apron. No mention of debris in the basin.

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
Keechelus Dam	10/1/2018	The stilling basin appeared unchanged from the 2011 inspection. The observed 10-inch-deep hole located at the base of the left stilling basin wall, left of chute block No. 1 appeared unchanged. Also observed in the 2011 inspection, on the right side of chute block No. 1, there was approximately 12 inches of a reinforcing bar exposed that also appeared unchanged. The drains in chute blocks Nos. 1 and 3 were clean and clear with no flow observed. There was minimal relief on and around the chute blocks. Minimal relief was found throughout most of the upstream basin. Generally, 3/4-inch relief was observed on the basin floor from the dentates to approximately 27 feet upstream with up to 2 inches of localized relief. Concrete relief of 1/4 inch and surface irregularity were observed around the dentates.
Keene Creek Dam	8/6/2014	The entire floor of the basin was covered with up to 30 inches of silt. This quantity of material was about the same as was reported during the 2006 inspection. The chute blocks and relief drains were buried, and flow through these drains is likely restricted or blocked. Although, largely buried in silt, the divers were able to feel along the concrete of the dentates and noted some damage to the concrete. The degree of damage is difficult to judge given the lack of visibility and silt coverage. Angular and sub angular cobbles and rocks up to 14 inches in diameter were found sporadically throughout the basin. The degree of coverage is difficult to estimate given the silted in nature of the stilling basin. The condition of the basin appears largely unchanged from previous inspections going back to 2000. The facility should be examined again on the normal Review of Operation and Maintenance schedule.
Keswick Dam	8/31/2016	The spillway stilling basin was in satisfactory condition however there were areas that showed relief in the concrete.
Keyhole Dam	No dive report found.	Spillway is a flip bucket with riprap line discharge channel. 2016 Comprehensive Review states that a dewatered examination of the stilling basin was performed in 2009. Not a type II or type III basin. Small volume of sediment and gravel was removed from the stilling basin; no damage to the basin floors, walls, chute blocks, or dentates was present.
Kirwin Dam	3/31/2000	The majority of the chute block and dentate damage appeared to be at and above the water line, undoubtedly from freeze thaw action. Previous patching and repairs have been made to several of the blocks, dentates, and end sill; however, a significant portion of the repairs do not appear to have been successful or are continuing to deteriorate. Several areas of exposed rebar were observed along the concrete end sill and dentates. The stilling basin floor appeared to be in satisfactory condition.
Kortes Dam		1974 dive report does not mention stilling basin. The 2016 Comprehensive Review Examination Report does not mention a stilling basin. The spillway chute connects to a spillway tunnel which discharges into the river through the right bank downstream of the dam. The spillway and tunnel have a history of cavitation damage.
Lewiston Dam	9/15/2016	The outlet works stilling basin was found to be free on concrete deterioration, cracks, exposed reinforcement, and no ball milling, or other deficiencies were observed. The dentates of the outlet works stilling basin were in good condition with no chipping or deterioration of the concrete observed. Approximately 20 sub-angular cobbles up to

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
		6 inches maximum dimension were observed at the downstream base of the dentates. Photographs show exposed rebar downstream of the dentates. The floor of the stilling basin has no organic covering but has up to 3/4 inch of concrete relief. There was no exposed rebar in the floor of the stilling basin. The chute blocks in the stilling basin were in good condition with no chipping or deterioration of the blocks noted. The spillway stilling basin appears to be in satisfactory condition with very little rock or debris observed in the basin and up to 1-inch of concrete relief observed on the floor.
Lily Pad Diversion Inlet Dam		The chute blocks and dentates were in excellent condition. No rocks were found within the basin, but only a limited amount of the floor was inspected.
Little Panoche Detention Dam	6/1/2009	Water has never flowed through the glory hole spillway structure into the spillway stilling basin. There is a layer of fine sediment 2 to 3 feet thick throughout the basin. The concrete in the outlet works stilling basin is in good condition, with no damage noted on the walls, floor, dentates, or chute blocks. A layer of fine sediment and/or organics was noted on all surfaces. Drains in the chute blocks were clear. The floor of the basin from the dentates to 20-feet upstream was 40 percent covered with angular rocks 3-12 inches in size.
Little Wood River Dam	5/24/2018	Annual exam report indicated that the outlet works stilling basin showed no evidence of degradation or erosion.
Lost Creek Dam	11/12/2014	The outlet works stilling basin is in good condition. There is minor chipping on the downstream faces of the chute blocks and the horizontal surface of the dentates, but the rest of these structures are in good condition. Concrete erosion on the floor is minimal. A gravel/cobble bar containing 3 cubic yards of material was located in the downstream left comer of the basin, covering an area 10-feet by 10-feet to a maximum depth of 1 foot. The spillway stilling basin is also in good condition. Several 18 to 24-inch boulders were found on the sloping surface at the upstream end of the basin, but none were found within the basin. These boulders were angular and did not appear to have moved about within the basin. They may have been thrown in from above. Fine grained sediments covered much of the structure, reducing visibility to near zero and limiting much of the inspection to feel. Minor chipping of the horizontal dentate surfaces was the only concrete damage noted, everything else was smooth.
Lovewell Dam	4/4/2008	The concrete edges of the walls, chute blocks, baffle blocks, and slab were sharp and well defined. The floor slab concrete ranged from smooth to slightly rough where surveyed.
Mann Creek Dam	8/31/2016	Spillway stilling basin all exposed concrete surfaces were in good condition, with no signs of recent erosion. The outlet works stilling basin had an accumulation of sand and gravel sized material which formed a 6-foot-long bar downstream of the chute blocks. There was an 1/2 inch concrete relief was noted between the sand gravel bar and the dentates. No damage was noted on the chute blocks or dentates.
Marble Bluff Dam		Combined stilling basin is rock lined.
Mason Dam	4/11/2017	HAS FLOW DEFLECTOR
McPhee Dam	3/17/2016	The spillway stilling basin was in excellent condition. All observed concrete surfaces were sound and smooth, with no signs of erosion or

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
		deterioration noted. Although the presence of sediment and organic deposits made it impossible to inspect the entire floor area, inspection of random localized areas throughout the floor indicated no concrete erosion problems. Inspection of the spillway basin would be recommended after a large spill to determine the whole extent of the condition of the basin. The outlet works stilling basin was in satisfactory condition with little to no deterioration of the concrete surfaces of the structure noted.
Medicine Creek Dam	1976	All concrete examined was in good condition. The dentates showed no wear.
Meeks Cabin Dam	7/17/2009	OW Stilling Basin was free of rock and woody debris but exhibited signs of erosion with typical relief of 1/4 to 1/2 inch and maximum relief of about 2 inches. The 6 chute blocks all exhibited chipped and rounded edges. Exposed rebars were found on the downstream face of the left most dentate. SW Stilling basin was cleared of debris except for some small woody debris piles less than 4 inches deep around the chute blocks.
Merritt Dam	10/5/2018	The spillway stilling basin floor could not be examined, and dry packed grout holes could not be located because material in the basin covered the floor. The surfaces of the concrete dentates had minimal relief and the edges of the chamfers were observed to be sharp. Underdrain outfalls in the chute blocks were observed to be patched with cement that is smooth with the vertical face of the chute blocks and performing well. The riprap downstream of the basin showed no indication of movement or degradation and the contact with the concrete end sill was buried. If a large sustained flow is released through the spillway, rock may move into the basin mainly from the river downstream and cause ball milling or erosional damage to the concrete surfaces of the spillway stilling basin. The surface of the concrete floor of the river outlet works stilling basin appears to be smooth to undulating with areas of significant erosion up to 3-inches deep on the left side downstream of the chute blocks. No dry pack grout holes, from the 2017 grouting operations, were located in the concrete floor of the outlet works stilling basin. There are rocks up to 14-inches in maximum dimension resting upon the sediment with which the concrete end sill was buried. The surfaces of the concrete dentates had minimal relief and the edges of the chamfers were observed to be sharp. Scattered 8-inch and smaller rounded rock was present at the base of the left wall of the river outlet works basin and appears that some of this material is eroding the concrete floor and lower portion of the walls in the outlet works stilling basin. Underdrain outfalls in the chute blocks were observed to be patched with cement that is smooth with the vertical face of the chute blocks and performing well. If a large sustained flow is maintained through the outlet works, rock in this stilling may result in ball milling or erosional damage to the concrete surfaces in the basin.
Minatare Dam	No Dive Report found. 2012 CR report	The concrete of the discharge chute walls, floors, energy dissipators, and stilling basin exhibits considerable deterioration, but continues to be structurally sound and functioning as designed. Therefore, the

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
		discharge chute and stilling basin are considered to be in fair condition. Not type II or III stilling basin.
Minidoka Dam		No mention of stilling basins in recent dive reports.
Monticello Dam	5/2/2018	All examined structures were in excellent condition.
Mormon Flat Dam	No dive report found	No spillway stilling basin. No mention of outlet works stilling basin in the 2012 Comprehensive Facility Examination Report.
Morrow Point Dam	8/17/2011	The spillway stilling basin was in very good condition with the concrete relief of¼ inch at the floor and sidewalls. A localized area of concrete with 1-to 2-inch concrete relief was noted on the left downstream sidewall. No exposed rebar was noted. Wall and floor joints were tight and smooth with no offset noted. Weep holes were partially filled with a mixture of organic material and sand. No flows were noted in the weep holes.
Mountain Park Dam		Plunge Pool
Navajo Dam	5/19/2017	Currently, there is no evidence that the material in the spillway stilling basin has been ball-milling enough to cause any appreciable erosional damage to the concrete. The outlet works stilling basin was in very good condition. The minor concrete erosion of approximately ¼-inch relief (documented in 2008) does not appear to be increasing.
Newton Dam	12/12/2008	The spillway stilling basin contains approximately 70 yd3 of fine grained sediments, same amount as the 1997 examination. The floor of the stilling basin was inspected by touch and it was found to be smooth except in the chute block area where the floor contained up to 1 inch of concrete relief. The chute blocks and dentates were smooth with no concrete damage. The outlet works stilling basin contained few angular to sub-angular cobbles and boulders. The concrete surface was smooth. The concrete surfaces of the chute blocks and dentates were smooth with no damage noted.
Norton Dam	10/5/2018	No mention of condition of outlet works stilling basin was found. Spillway stilling basin is too wide for flow deflectors.
Ochoco Dam	2/27/2012	The overall condition of the outlet works stilling basin was good, with only minor area of erosion noted. Four sections of rebar, with the top third exposed and each approximately 12 inches long, were noted in the floor near the upstream end. No rock or gravel deposits were noted in the basin.
Olympus Dam	7/10/2003	Too wide for flow deflector.
Owyhee Dam	3/30/2017	Morning Glory spillway connects to spillway tunnel which then discharges through a circular discharge portal into a discharge area.
O`Neill Dam		A spillway is located in the left abutment of the dam that consists of an uncontrolled glory hole inlet structure, an 11.75-foot-diameter conduit, a stilling basin, and a discharge channel. The design capacity of the spillway is 3,250 cfs at maximum water surface elevation of 228.0 feet. The spillway has never discharged.
O`Sullivan Dam	Annual Site Inspection Report 4/10/2018	The Potholes East Canal Headworks conduit stilling basin was inspected as part of the Annual Examination Report and nothing of note was observed.
Pactola Dam	10/5/2018	Most concrete surfaces were sound and smooth, with no cracking or spalling and only minor relief. The exception, and an area of some concern, is the chute blocks and concrete between the chute blocks.

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
		As noted above, there are signs of ball milling causing some erosion to the chute blocks and the concrete between the chute blocks. Special attention should be given to this area during the next inspection.
Palisades Dam	12/19/2016	The 2017 CR report indicates After 2003 repairs to the floor and walls of the stilling basin, an inspection in 2007 showed that additional damage had occurred. Repairs to the floor, splitter walls and side walls of the stilling basin were performed in 2012 and 2013. The stilling basin was inspected during dewatered conditions during a 2013 transfer inspection after the 2013 repairs. A short concrete wall (weir wall) oriented perpendicular to the direction of flow is located in the tailwater pool at the downstream end of the stilling basin. The wall separates the stilling basin from the river channel to enable Field Office personnel to dewater the basin for inspection and maintenance purposes.
Palmetto Bend West Dike	11/19/1984	The concrete in the chute blocks, floor, and dentated sill at the downstream end of the stilling basin were found to be in excellent condition.
Paonia Dam	2/23/2017	The combined basin contains an estimated 1,400 cubic yards of fine-grained sediments. The material was loose, and a folding ruler could easily be pushed vertically through the material to the floor. The visible portions of the dentates contained no notable damage. The boulders found in the basin during the 2009 inspection were angular in shape and may still be in the basin under the fine-grained sediments. The fine-grained sediments may be easily transported downstream the next time the basin receives flushing flows.
Pathfinder Dam	No dive report found	2017 Comprehensive Review Examination Report state spillway discharges into rough channel of natural rock and plunges into North Platte River below. No mention of outlet works stilling basin.
Pilot Butte Dam	No dive report found	O&M exams suggest the spillway is not used too often. The section below the waste way, including the stilling basin, was in poor condition in 1966. The current condition is unknown or not reported in a dive report. No stilling basin downstream of spillway chute.
Pineview Dam	3/4/2008	One large cobble and boulder bar about 4yd3 in volume was located along the right wall between the baffle blocks and the dentates. Substantially less rock debris was present in the basin that the 45 yd^3 estimated during the 2001 underwater inspection. Rock was removed manually from the basin since the last underwater inspection. The concrete on the baffle blocks and the floor patch was generally smooth and in excellent condition. The concrete in the rest of the basin and on the dentates had exposed aggregate with 1/4 to 1/2-inch relief.
Pinto Dam	No dive report found	The 2013 Comprehensive Review Examination report indicates the stilling basin is in satisfactory condition, with no significant cracking, spalling, deflections, or deformations. The stilling basin exits into a trapezoidal riprap-protected discharge channel, which in turn exits into Brook Lake.
Platoro Dam	6/13/2007	Stilling basin is a natural rock-lined portion of the original river channel. The basin was in very good condition, with only one void noted in the contact between the valve house foundation and the bedrock.

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
Prosser Creek Dam	2/25/2014	All chute blocks were clean and free of gravel or debris. The two chute block underdrains were also clean of any debris. A minor amount of pea gravel was present in the invert of each drain and was removed by the divers. All chute blocks were well defined with sharp edges. The concrete walls in the outlet works stilling basin were smooth with form marks visible. The dentates and floor were clean and free of debris. The contact at the basin walls and floor was tight with square surfaces and no visible damage. The basin floor exhibited less than ½ inch erosion in the concrete. Divers removed several rounded cobbles, 4- to 5-inches in size, which were on the basin floor. The concrete dentates were inspected and no damage was found. The concrete edges contained square comers with no visible damage. The outlet works stilling basin was free of previously mentioned gravel bar and debris with the concrete in excellent condition.
Rattlesnake Dam	9/21/2018	The 2017 Comprehensive Facility Review Examination Report indicates the concrete spillway chute transitions to an earthen discharge channel on the downstream end. The outlet works discharge channel runs downstream for about 300 feet before passing under the access road through a culvert. Flows through the channel then cascade down the hillside and enter into the Rattlesnake Creek bed below.
Red Fleet Dam	3/8/2017	The assessment of the two scour holes along the left bay of the river outlet stilling basin revealed that their depth had increased an approximate 3/4 inches since the 2009 inspection. It is recommended that these scour areas continue to be monitored during future inaccessible feature inspections. Underwater visibility was poor for SCUBA divers during the spillway stilling basin assessment, which contributed to the inability to locate the chute blocks. The upstream left corner of the spillway contained heavy vegetation debris both surface and subsurface. The basin was reported to have been last cleaned in the mid-1990s; the last spill occurred in the spring of 2016. A recommendation should be considered at the next CR to remove the heavy vegetation debris to eliminate any potential flow impediments and maintain spillway performance.
Red Willow Dam	12/7/2008	The purpose of the diving activities was to remove the existing drain plugs and clean the outfall pipes in the outlet works stilling basin and to remove sediments from the spillway stilling basin drain outfallls in an attempt to determine if the drains were operating correctly. There was no mention of erosion or abrasion damage.
Ridges Basin Dam	No dive report found	The 2013 Comprehensive Review Examination Report indicates the outlet works discharge chute transitions downstream into two 48-inchdiameter precast concrete pipes which lead into a Type IV impact basin, then discharges downstream into Basin Creek. The concrete of the impact basin is in satisfactory condition with no evidence of cracking, spalling, damage, or deterioration. The walls of the impact basin are straight with no evidence of settlement or displacement.
Ridgway Dam	4/18/2016	Model study in 1996 investigating abrasion damage in outlet stilling basin from recirculating flows. From the 2016 dive report. The outlet works stilling basin does not appear to have changed or degraded from the 2009 examination. The continued use of the new separate powerplant will limit how much flow is released through the outlet works stilling basin. Minor concrete erosion surrounds the chute

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
		blocks (about ½ inch of relief); however, the erosion has progressed little from the 2009 examination. The overall condition of the spillway stilling basin is satisfactory. The concrete of the structure (floors, walls, dentates, and chute blocks) appears to be generally smooth with no signs of significant damage or deterioration. The floor of the spillway stilling basin is generally clear of rock, sediment, and debris; however, approximately 50 cubic yards of woody debris is interspersed with small sediments surrounding the chute blocks. No visible damage is on any of the concrete surfaces in this area of accumulation. The basin may clean itself during the next spill event, or additional wood pieces may accumulate.
Rifle Gap Dam	6/4/2014	The combined stilling basin was in good condition with sediment 9- to 18-inches thick covering most of the floor area. Along the left wall of the basin the sediment is 18-inches thick and along the right wall it is 9-inches thick. A few scattered cobbles and boulders were noted throughout the basin. The angular nature of the scattered rock indicated that very little erosional activity was taking place.
Ririe Dam	9/19/2018	The outlet works stilling basin appeared in good condition, with no exposed rebar or rock accumulation noted in the basin. The abrupt flip bucket wall at the downstream end of the stilling basin had a 2 to 4 inch thick layer of very fine silt build-up on the left side and center.
Roza Diversion Dam	5/11/2007	It appears that the top of the chute blocks and downstream faces of the dentates have continued eroding since the 1977 examination, but at a relatively slow pace.
Ruedi Dam	11/18/2015	The outlet works stilling basin appeared to be in satisfactory condition. No exposed reinforcement was in the chute blocks, dentates or walls. Only minor rust consisting of rust nodules on the edges of the steel stop log slot channels was observed. Concrete surface relief from 1/8-inch up to 1½ inches was in the floor of the outlet works stilling basin. Several areas of concrete spalling were in the left bay on and upstream of the chute blocks. Additional spalling and patching in the concrete floor was in the right bay of the stilling basin. Areas of ball milling are downstream of the chute blocks, in both the left and right bays of the outlet works stilling basin. This area should be inspected for detrimental damage during the next (and future) inspection, and any rock found in the area of the ball milling should be removed. If large flows are released through the basin, the rock present could result in detrimental ball milling and possible extensive damage to the concrete. Although not a dam safety concern, the next inspection should closely examine the four formed holes in the basin floor upstream of the dentates to determine the condition of the holes and what was used to plug them. The combined auxiliary outlet works and spillway stilling basin appeared to be in satisfactory condition, with no exposed rebar or deterioration of concrete noted. A large amount of rock and debris is located around the chute blocks and beneath the Rocky Fork Creek bypass. If a spill occurs in the spillway, or a large flow is discharged from the auxiliary outlet works, debris in the stilling basin has the potential to severely erode and damage the concrete. Should a major spill occur, it is recommended that an inspection be scheduled as soon as possible to determine if the stilling basin sustained any damage.

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
Rye Patch Dam	5/11/2001	Too wide for flow deflector. Stilling basin had a large sand/cobble bar of 400 cubic yards.
Sanford Dam	11/10/2010	The river outlet works/M&I intake structure, flood control outlet works stilling basin, spillway stilling basin, and river outlet works stilling basin all appear to be in satisfactory condition…Sediment made it impossible to inspect the floors of the stilling basins, but inspection of the walls indicate no erosion problems in the concrete. Rocks found in the stilling basins, also found in 2003 inspection, appeared to be inactive and not impacting the concrete surfaces of these features.
Scofield Dam	5/24/2007	Repairs were made to the spillway in 2007 and 2008. The 2007 dive report indicates the outlet works stilling basin chute blocks had erosional damage and exposed rebar, but erosional forces had progressed slowly since the 2001 examination period. No accumulation of material in the spillway stilling basin between the chute blocks and the dentates was noted.
Scoggins Dam	1/30/2017	The outlet works stilling basin, and the spillway stilling basins were found to be in excellent condition. The condition of the floor, walls, dentates, and chute blocks in both basins have remained relatively unchanged when compared to previous inspections.
Seminoe Dam	3/2/2011	The outlet works stilling basin appears to be in generally satisfactory condition.
Shadehill Dam	No dive report found	The 2013 Comprehensive Review Examination report states that "The visible portions of the concrete stilling basin are in satisfactory condition, with no significant deflections, offsets, cracking, or concrete deterioration. A 72-inch-diameter steel pipe (extension pipe from the outlet works stilling basin) discharges into the service spillway stilling basin (photos CE-44 and CE-45); the outfall pipe is in satisfactory condition. On September 20, 2012, the spillway stilling basin was dewatered and examined [5]. The memorandum describing the 2012 examination states, "the 2005 Belzona repair continues to be in excellent shape..." The memorandum indicates there are a few areas of exposed reinforcing steel on the right upstream end of the stilling basin; and that overall, the stilling basin is in good condition and only requires minor concrete repairs and spot patching."
Shadow Mountain Dam	9/25/2000	There are nine chute blocks in the basin. There were areas of scour with exposed aggregate between the chute blocks on the upstream end of the stilling basin and on the chute blocks. Erosion was also noted on the chute blocks. The deepest area of scour was measure at 1 in deep on the first chute block on the north side of the stilling basin. No exposed rebar was identified in the basin. The nine baffle blocks at the end sill were found to be in good condition.
Sherman	8/24/2000	The spillway discharges each year but has never overtopped the morning glory inlet by more than 0.2 feet. Because the spillway has never experienced a large cleansing flow, the entire floor of the stilling basin was covered with 4 feet of boulders, cobbles, gravel, sand, and fines. Beginning at the downstream end of the stilling basin to the first construction joint upstream, angular boulders up to 18 inches in maximum dimension covered 100 percent of the basin floor. One of these boulders was turned over and staining was observed, indicating that the boulder had been lodged in the sediment for some time...The concrete sidewalls of the stilling basin exhibited no signs of damage or

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
		excessive wear. The floor of the (outlet works) stilling basin showed no signs of deterioration.
Silver Jack Dam	4/1/2016	Divers found the repaired concrete floor in both bays to be in good condition. Exposed aggregate was on the surface of the repair, and the repair had a sandpaper texture. No eroded areas were found, and there was no relief on the top of the repair. Contact with the side walls and the upstream and downstream concrete surfaces were also in excellent condition. All of the dentates were in good condition with well-defined edges and chamfers. The dentates showed a minimal amount of concrete relief, up to ⅛-inch or less. The chute blocks and the sloping floor upstream of the chute blocks was also in good condition. The sloping floor was smooth, and only minimal relief found on the chute blocks. No woody or rock debris was found within the stilling basin. The stoplog guides were clean, with a smooth sill underneath.
Soldier Creek Dam	4/25/2013	The outlet works stilling basins appear to be in satisfactory condition. The erosion and abrasion is considered to be minor. The plunge pool area appears to be in satisfactory condition, and there is no evidence of areas of excessive erosion or blocks of missing bedrock. Both basins have flip buckets at the downstream end that discharge into a plunge pool.
Soldiers Meadow Dam	3/28/2011	No mention of stilling basin in most recent dive report. The 2016 Comprehensive Review Examination Report indicates the downstream side of the spillway overflow structure, stilling basin and downstream road culverts are clear, clean, and in satisfactory condition.
Spring Creek Debris Dam	4/25/2017	The basin was in overall satisfactory condition. There was some minor vegetation and cobbles in the basin, but this is limited and minor. There was also spalling on the tops of Dentates #2 and #3, but this is also minor. The most significant finding is the buildup of 4 feet of organic growth in the basin given that the basin had been cleaned out in 2011.
Stampede Dam	8/16/2011	Spillway Stilling Basin was dewatered and inspected in the dry in 2010. The 2004 dive report stated approximately 20 cubic yards of angular to sub-angular rock debris was located in the vicinity of the chute blocks. The concrete surfaces of the chute blocks were smooth with sharp corners and chamfers. The concrete floor surrounding the chute blocks and down to the dentates contained up to 1/2-inch of erosion relief. In the right bay there was a 2-inch deep layer of organic material in the chute block area. In the right bay, the No. 3 dentate (numbered left to right, looking downstream) had one exposed rebar. The bar was exposed approximately 7 inches in the horizontal direction and exposed one third to one-half of the diameter of the bar. The exposed bar was located 2 inches off the floor on the upstream right side of the dentate (this was about the same damage reported during the November 1997 and 2004 inspections). The remainder of the concrete in the right bay dentates was in good condition with square concrete comers. The concrete in the left bay dentates was in good condition with square corners and smooth sides. The contact between the concrete and armor rock on the downstream slope of the dentates was tight with no undercutting or erosion noted.

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
Starvation Dam	3/8/2017	The river outlet works stilling basin had aggregate exposure of 1/8 inch on dentates, algae growth on walls, and fine sediment of the basin floor to a depth of approximately 1/16 inch. A pile of rounded cobble, approximately 6 feet in diameter, was observed about 10 -15 feet downstream of chute blocks, with the cobble varying in size between ¼ and 12 inches in diameter. Chute blocks No. 1 and 2 also had 6-8 inches of sediment build-up. The spillway stilling basin floor was covered with 18 inches of sediment.
Stateline Dam	2/2/2009	The spillway stilling basin contained a large amount of fine sediments and gravel. All of the drains coming into the chute blocks were completely covered. It is recommended that this material be removed from the basin before it causes damage. In the event of a large or prolonged release through the spillway, ball milling of the gravel could cause significant concrete damage. In the outlet works stilling basin, he two outside chute blocks have a 6-inch drain pipe in them. The drains were clear with a small amount of coarse sand present. The two chute blocks with drains showed considerable concrete damage with exposed rebar along the sides of the blocks. As in previous inspections, the remaining concrete in the damaged areas revealed aggregate up to 1-1/2 inch diameter. The exposed rebar was shiny, with no rust, indicating on-going erosion. The two interior chute blocks were in good condition, with only minor concrete erosion noted. Note that the damage to the left chute block, left side was not noted in the previous examinations. This could indicate an on-going and increasing deterioration process. The floor of the basin exhibited increasing concrete erosion damage from 1/4 to 1/2 inch in 2003 to up to 2 inches in 2008. The downstream dentates were in good condition with only minor chipping and erosion noted.
Steinaker Dam	No mention of stilling basin condition in dive reports	The stilling basin has wave suppressor installed. The 2017 CR report indicated the Uinta Water Conservancy District (UWCD) operators indicated that they dewater, clean, and inspect the spillway/outlet works stilling basin every fall as part of regular operation and maintenance practice. The stilling basin was dewatered and inspected in 2016. Operators continue to monitor the wall offsets and indicated that the condition of the structure had remained the same as reported in the 2013 PFR examination report which stated the basin was found to be in satisfactory condition overall, with some minor vertical cracking in the right wall, and spalling near the dentates. No recommendations were issued.
Stony Gorge Dam	9/16/2016	Ongoing issues with undercutting at the downstream end of the stilling basin apron have been reported. No issues relating to rock, abrasion, or erosion of concrete surfaces were reported.
Sugar Loaf Dam	11/5/2010	Erosion of the concrete in the right side of the outlet works stilling basin floor has exposed the reinforcing steel around the joint at Station 14+79.50. This exposure extends down to the second layer of (longitudinal) reinforcing steel. The need to repair the floor of the outlet works stilling basin should be evaluated. There does not appear to be any substantial damage in the spillway stilling basin structure. While there is a deposit of cobbles in this structure, it is relatively minor and would not be expected to damage the concrete unless the spillway was to operate for a long duration. Removal of this material

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
		would only be justified at this time if it could be coordinated with other activities.
Sumner Dam	6/3/2005	The end sill of the stilling basin was found to be in satisfactory condition, with no signs of erosion. The upstream edges of the end sill dentates were slightly eroded, with rounding of the edges and some exposed aggregate. Between dentate Nos. 4 and 5, the concrete on the vertical and horizontal edges was eroded to a depth of approximately 6 inches. The majority of the stilling basin floor was abraded, exposing the underlying aggregate, leaving about 1/4 to 112 inch of surface relief. The large boulders, located within the basin area, should eventually be removed to prevent concrete damage to the floor due to ball milling during future spillway discharges. A depositional bar of sand, gravel, and cobbles was encountered downstream of chute block Nos. 13, 14, and 15. No evidence of damage to the basin floor was observed in this area. All 15 chute blocks were found to be in satisfactory condition with no chipping, scouring, or erosion. No significant sediment buildup or blockage of the drain holes was found that could potentially block discharges. A large amount of rock, sediment, and debris was located between chute block Nos. 1 through 7, with only minor amounts of material upstream or downstream of the chute blocks. The cobbles and boulders encountered between the blocks were sub angular in shape and ranged in size from 6 inches to as large as 2-1/2 feet in diameter. The rocks were underlain by a layer of fine gravel approximately 6 inches in depth. The nature of the rock and debris indicated that it probably originated from a landslide that occurred several years ago, on the right slope above the spillway stilling basin. The rock and debris should be removed from the chute and stilling basin to prevent potential ball milling damage during future spillway discharges. Conditions at the combined spillway outlet works stilling basin have not changed significantly from the inspection personnel in April 1999.
Taylor Park Dam	6/2/2011	The spillway stilling basin is in good condition. The basin concrete, under water, is still smooth. Consideration should be given to removing the debris in the basin in its entirety. The outlet works stilling basin floor and sides contained a combination of in-situ bedrock and grouted riprap. The right side and basin floor were comprised of mostly bedrock with scattered pockets of gravel to boulder sized rock. Left side of the basin contained a combination of loose angular riprap, grouted angular riprap, and loose angular and rounded cobbles and gravel.
Terminal Dam	No dive report found.	No mention of a stilling basin in the 2009 Comprehensive Review Examination Report.
Theodore Roosevelt Dam	No dive report found.	2012 Comprehensive Review Examination Report indicated that the spillway discharges into a plunge pool. The concrete of the spillway gate bays, walls, gate hydraulic cylinder platforms, and flip buckets is in satisfactory condition, with no large cracks, spalls, or other damage or deterioration.
Thief Valley Dam	8/27/2014	Left and right stilling basins are each reported to be in good condition. Each have histories of exposed reinforcing bars and erosional depressions which have been reported and are being monitored. Neither is a type II or Type III stilling basin.

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
Tiber Dam	1/7/2011	The auxiliary outlet works stilling basin is in good condition, with only minor amounts of concrete erosion noted. Some erosion pockets, 5-7 inches deep exist between the chute blocks. The basin is covered with a 1-inch thick layer of organic material. The river outlet stilling basin was found to be in very good condition. No mention of abrasion damage caused by recirculating flows.
Tieton Dam	8/6/2018	Only plunge pool was inspected. (2108 Dive Report) From the 2013 Comprehensive Review the recommendation was to "Repair the deteriorating concrete on the right side of the spillway stilling basin, from the downstream end of the stilling basin upstream to the downstream end of the concrete overlay of the right spillway chute wall." Not a type II or type III stilling basin.
Trenton Dam	11/10/2010	The spillway stilling basin appears to be in satisfactory condition. The concrete did not have any spalling nor was there any exposed reinforcement in the chute blocks, dentates, or walls. An 18-inch-long piece of reinforcement is present perpendicular to the wall just upstream of the dentates on the left wall. The reinforcement does not appear to be a structural component of the wall. If large flows are released through the basin, the large cobbles/boulders present could result in ball milling and possible damage to the concrete. In addition, flows through the basin could move the 55-gallon drum, car door, and long pipe which could result in damage to the concrete. These should be removed from the stilling basin if it is cleaned in the future.
Trinity Dam	4/29/2015	The outlet works stilling basin and rock barrier were in fair condition with no structural damage noted. However, all the concrete surfaces were scoured to at least the aggregate and in many places reinforcing bars were exposed. In some areas the bars were completely eroded around the entire perimeter. The examination results were similar to those reported in 2006; however, a large accumulation of pea gravel and cobble bars were present. Similar algal growth and surface rust were observed on the steel rock barrier and accumulated gravel and cobbles remaining on the outside of the rock barrier were generally in the same locations as noted in the 2006 examination report. A new accumulation of cobbles and some large boulders were on the inside of the barrier structure. The spillway flip bucket was in good condition with its structural integrity intact. The undercut area located on the downstream side of the foundation concrete was not found but should be monitored on future underwater inspections.
Twin Buttes Dam	9/7/2010	The outlet works intake structure and the exposed concrete sections of the outlet works and spillway stilling basins were found to be in good condition. There were no significant signs of concrete damage or deterioration on these structures.
Twin Lakes Dam	2/17/2009	The inspection of the spillway stilling basin showed no damage or deterioration, as expected due to the fact that the spillway has never operated.
Twin Lakes Dam	7/5/2011	At the center of the top edge of the upstream face of the dentate against the right wall, an area of chipped out concrete was observed. This area of chipped out concrete was 2 inches high, by 3 inches wide, by up to 1 inch deep. At the middle dentate in the right side bay, a damaged area of concrete 4 inches high, by 18 inches wide, by 4 inches deep was observed at the top left hand corner of the upstream

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
		face of the dentate. Concrete relief on the dentates and on the floor at the downstream end of the basin was about h-inch. The concrete relief of the floor, progressing upstream, increased from 1/4-inch up to 1 and even 2 inches in the concrete adjacent to the chute blocks due to ball milling. This ball milling resulted in scalloping of the floor close to the chute blocks in the right bay of the stilling basin.
Twitchell Dam	No dive report found.	2012 Comprehensive Review Examination Report indicated underwater inspections of the stilling basin could not be conducted in the past due to sediment deposition within the stilling basin and relatively shallow water depth covering the sediment. Now that the sediment has been removed, underwater inspection of the structure can be accomplished.
Unity Dam	8/31/2016	The amount of material noted in the stilling basin during the 2009 underwater examination appears similar to the amount observed during this inspection; however, the location appears to be shifting somewhat. This is most likely due to spring releases through the spillway. The amount of debris is estimated at 70 to 75 cubic yards of debris as noted during both the 2003 and 2009 inspections. All exposed concrete surfaces were in good condition, with no signs of recent erosion.
Upper Stillwater Dam	3/8/2017	Overall the spillway stilling basin is in fair to satisfactory condition. Angular rock covered approximately 25 percent of the basin floor. Rocks ranged in size from one inch to 24 inches in diameter. The larger diameter rocks were located towards the downstream wall. Piles of smaller rock located by the upstream wall ranged in size from 3 to 4 feet in length. Sediment was present on the basin floor in various areas and ranged from a light dusting to 5 inches in depth with the greatest deposition on the upstream wall. Piles of woody debris and vegetation were located in the upstream right corner and along the upstream wall. The majority of the concrete surfaces were smooth except for the upstream wall that had 1/4 to 1/8 inch of erosion. Erosion was observed on the basin floor towards the upstream wall. The erosion area runs parallel to the upstream wall and is most likely the area where the water hits the basin floor during spill events.
Vallecito Dam	8/16/2011	The overall condition of the combined outlet works and spillway stilling basin was very good. All concrete, where visible, appeared to be smooth with minimal relief of 1/4 inch. No offsetting joints or exposed rebar was noted.
Vega Dam	11/14/2014	The spillway stilling basin is in good condition. No rocks were found within the basin, only a small amount of gravel found at the base of the chute between the chute blocks. The walls are smooth, and the upstream end of the basin floor shows relief of 1/8 inch, with the floor in the downstream end of the basin being smoother than that. Chute blocks and dentates are in fair condition, with some damage around the edges. Drains in the chute blocks were found to be clear, with no flows detected.
Vega Dam	4/9/2002	Approximately 5 cubic yards of angular cobbles were found within the outlet works stilling basin. Minor erosion was noted on the horizontal floor, with up to 3/4-inch relief in the concrete. No exposed rebar was found. The sloping floors at either end of the basin were smooth, as were the walls. Dentates and chute blocks were in good condition,

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
		with only minor chipping. Although the outlet works were shut down and drained, a minimum flow of 1 to 2 cubic feet per second could be maintained for fishery concerns during future underwater examinations.
Virginia Smith Dam	9/24/2012	The previously reported sand and rock material found in the spillway stilling basin in 2004 was not found during this inspection. Instead, some coarse sand and grout slop were found on the floor of the basin, but no flow-related damages or concrete surface relief were noted anywhere in the basin. It also appeared that coarse sand has re-settled over the top of the end sill, where riprap was previously removed and stop logs installed during the spillway stilling basin modification completed in 2004. Dry pack repairs in this basin are also still intact. The river outlet works stilling basin appeared to be largely unchanged since the 2004 underwater inspection. The concrete floor surface relief in the right bay may have doubled since those reported in 2004, increasing from a maximum of 1/4 inch in 2004 to a maximum of 1/2 inch in this current inspection. There was no change in the concrete floor surface relief noted in the left bay. Consistent with previous reports, the right bay continued to exhibit greater surface relief in the concrete floor than those in the left bay. Dry pack repairs were still intact.
Wanship Dam	1/29/2015	The outlet works stilling basin contained a gravel bar of 1 cubic yard on the left side of the basin downstream of the chute blocks. The chute and floor have less than 1 inch of concrete relief. The spillway stilling basin contains about 20 cubic yards of rock material upstream of the chute blocks. The chute slope and floor contain about 2 cubic yards of material from the broken right wall of the spillway chute wall. The other concrete surfaces in the basin display very little damage.
Warm Springs Dam	Dive reports contain no information about stilling basins.	The 2011 Comprehensive Review Examination Report indicated the combined spillway/ outlet works plunge pool is in satisfactory condition. No problems regarding excessive erosion of the plunge pool rock have been reported.
Wasco Dam	No dive report found.	The 2016 Comprehensive Review Examination Report indicated The visible sections of the stilling basin concrete walls were observed to be in satisfactory condition. The stilling pool and discharge channel are also in satisfactory condition with no significant obstructions to discharge. The last inspection of the inundated portion of the stilling basin occurred during a dewatered inspection in August 2015. During the 2015 inspection the condition of the concrete invert, lower side walls, and dentates were reported to be satisfactory
Webster Dam	11/10/1999	Spillway stilling basin is too wide for flow deflectors.
Whiskeytown Dam	10/3/2016	The spillway stilling basin was in good condition. The outlet works stilling basin was covered with gravel and cobbles up to 8 inches in diameter. The channel invert was relatively uniform, no scoured or mounded areas of rock…The Clear Creek channel downstream of the outlet works and spillway stilling basins was in good condition. There was no evidence of ongoing erosion in the basin.
Wickiup Dam	8/11/2011	Both bays are both in good condition. The chute blocks in both bays had concrete relief of 1 1/2-inches and dentates in both bays had concrete relief of 1 1/2- to 2-inches. With the exception of a small

Dam Name	Dive Report / Annual Report Date	Dive Report Findings
		area in the right bay, all erosional areas noted during the 2005 underwater examination have been repaired. The repaired areas are all holding up well. There was no exposed rebar noted anywhere in the basin.
Willow Creek Dam, CO	1993 RO & M EXAM REPORT	OW discharges to a stilling pool below dam. Spillway chute appears to terminate into a hillside gully.
Willow Creek Dam, MT	Dive reports contain no information about stilling basins.	The 2012 Comprehensive Review Examination Report indicated During this examination, the stilling basin was dewatered for inspection. The concrete dentates near the middle of the basin continue to exhibit erosion and exposed reinforcing steel. The concrete floor continues to exhibit significant erosion and exposed reinforcing steel. Recommendation 2008-2-E, to repair the deteriorated concrete sections of the outlet works stilling basin floor and chute blocks, in accordance with Reclamation Guide to Concrete Repair, is incomplete.
Yellowtail Dam	3/6/2017	The placed riprap appeared intact and not sufficiently disturbed by previous high flows through the stilling basin. No undercutting was observed at the downstream contact of the stilling basin. Any riprap that may have been moved or blown out by high flows did not appear to produce any harmful action against the downstream contact concrete

Appendix C - Draft Questionnaire for Facility Managers

Research Project - Flow Deflectors for Reduction of Abrasion Damage in Reclamation Stilling Basins

Physical model investigations conducted by Reclamation's Hydraulic Investigations and Laboratory Services Group in Denver, Colorado were used to develop standard guidelines for the design of flow deflectors to reduce stilling basin abrasion damage. Abrasion damage has been a long-standing problem for stilling basins throughout Reclamation. Model studies conducted to understand the problem assisted in developing cost effective solutions. For standard Reclamation type II and type III stilling basin designs, flow deflectors can be used to mitigate abrasion damage by redirecting flow currents responsible for carrying abrasive materials into stilling basins and recirculating them within the basins. Field evaluations of the stilling basins at Mason Dam and Choke Canyon Dam were conducted to validate physical model results and used to refine and verify the designs.

Two design approaches have been developed, one using basin velocity profiles measured in the field or in a physical model as the basis for a refined design, and a second simplified method using an oversized deflector that can be applied without the need for velocity profile data. An initial determination must be made whether stilling basin geometry matches closely with the design parameters presented in Reclamation's Engineering Monograph No. 25. If so, then the guidelines will be used in conjunction with measured velocity profiles to develop a deflector design for the basin. The range of stilling basin operations will help determine if one deflector is adequate, or whether two staggered deflectors are required to provide effective performance. An additional benefit observed in model investigations with flow deflectors in place, is that a type II basin can become hydraulically self-cleaning at flows well below design flow, whereas without a deflector in place, full design flow would normally be required to provide flushing action. Investigations conducted with the flow deflector installed in the type III stilling basins did not have the same self-cleaning tendency.

The current simplified guidelines for designing oversized deflectors will not require the time and expense associated with obtaining velocity profile data but are based on only one case study and need further development. The deflector design and placement are not optimized, and the size of each deflector is significantly larger. The oversized deflector does produce significant headloss that will also need to be accounted for. Additional research could reduce uncertainty that affects the determination of the deflector size and position, leading to smaller, more economical deflectors.

The developed guidelines are recommended only for stilling basins less than approximately 25 feet in width. Wider basins can effectively use flow deflectors to prevent materials from entering a stilling basin, however due to unique flow characteristics associated with the wider basins, a physical model study is recommended.

A recent inventory of Reclamation type II and type III standard design stilling basins, with widths of 25 feet or less, with evidence of rocks in the basin, and erosion or abrasion damage or history of exposed rebar and/or repairs for such damage has been assembled. The extent and/or pervasiveness of the damage is not clearly understood for each basin. Your facility has been identified as having damage that may be consistent with abrasion damage caused by recirculating flow and may benefit from flow deflector installation. To assist in this assessment effort, and the effort to develop cost effective abrasion damage mitigation solutions, at your earliest convenience, please give thought to these questions.

1. What are the location and extent of abrasion damage – depth of erosion, and location on walls, floor, or blocks of structure? Are there areas of exposed rebar?

2. What type of material is in basin –rocks, small sediment, fine-grained soil (silt/clay), metal or construction scrap, steel rebars, or other?

3. How did material enter the basin (if known) – thrown/dropped in, left by contractor, landslide, sloughing canyon wall, or carried in from downstream by recirculating flows?

4. If by circulation, do you know the location downstream from structure where material came from?

5. If possible, please describe the circulation pattern of water bringing material in.

6. Operating conditions for which damage occurred:

a. Structures operating – outlets, spillway, powerplant

b. Discharges and tailwater elevations

c. Time estimate for damage to occur – hours, days, weeks, years

7. What repairs have been made to the stilling basin?

8. Cost of repairs?

9. Can you provide photographs showing damage or flow conditions causing damage?

What is your interest level in a physical model study and/or field study to collect data and develop an optimized flow deflector for abrasion damage mediation?

Data Sets that Support the Final Report

- Share Drive folder name and path where data are stored:
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  2019-PRG-Flow Deflectors for Abrasion Damage Mitigation in Stilling Basins
- Point of Contact name, email, and phone:
  - Christopher (Kit) Shupe, cshupe@usbr.gov, 303-445-2143
- Short description of the data:
  - Copies of reference materials, including video of original model studies
  - Final report — drafts and final versions, figures, etc.
  - Spreadsheet containing inventory of Reclamation stilling basins
- Approximate total size of all files: 5.5 GB