Link River Dam Fishway Replacement Feasibility Study

May, 2001

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Prepared for
Bureau of Reclamation
Klamath Area Office

By

Bureau of Reclamation
Technical Service Center

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Submitted to:
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Link River Dam Fishway Concept Study

Study Objective

The Klamath Basin Area Office (KBAO) requested the Water Resources Research Laboratory (WRRL), Denver, Colorado conduct a study to investigate improving fish passage at Link River Dam. Link River Dam is located at the terminus of Upper Klamath Lake near Klamath Falls, Oregon, figure 1. The dam controls the elevation of Upper Klamath Lake and flow releases to Link River. The dam is considered a barrier to upstream passage of native fish species of Klamath Lake and the Klamath River system. This study proposes several fish passage concepts for improving upstream fish passage from Link River to Upper Klamath Lake.

Background

Link River extends for less than a mile between Upper Klamath Lake and Lake Ewauna. Link River Dam was constructed across a rock outcropping that formed part of a natural falls at the outlet of Upper Klamath Lake. About 600 ft downstream of the dam a series of falls still exist.

<u>Link River Dam (USBR, 2000)</u> Link river Dam was completed in 1921 and is operated by the Pacific Power and Light (PP&L) Company to provide hydroelectric power production and diversion of irrigation water. The reservoir, Upper Klamath Lake, is for the most part a natural lake that covers an area of 85,000 acres at reservoir water surface elevation 4143.3. It has an active storage capacity of 523,700 acre-feet between elevations 4143.3 and 4136 and an inactive storage capacity of 211,300 acre-feet between elevations 4136 and 4126. The dead storage volume below elevation 4126 has not been determined.

An unusual condition exists at Link River Dam in that hydraulic control of large outflows from Upper Klamath Lake is established at a reef located at the south end of the lake, approximately 0.4 miles upstream from the dam. A 100-foot-wide channel was cut through the reef to an invert elevation of 4131 feet when the dam was constructed; the remaining portion of the reef is at approximate invert elevation 4138. Because of the controlling influence of this reef, it is possible during large flood events to have reservoir water surface elevations in Upper Klamath Lake higher than the top of dam elevation of 4145.0, while water surface elevations between the dam and the reef are below the top of dam, provided that the dam gates are opened sufficiently to pass the water that flows over the reef. At maximum reservoir water surface elevation of 4143.3 feet, the maximum reef discharge is 8,500 ft3/s.

Link River Dam is a reinforced concrete buttress and slab diversion structure consisting of multiple slide gate and stoplog bays with a common operating deck at elevation 4145.0, see figure 2. It has a structural height of 22.0 feet, a hydraulic height of 8.0 feet, and a crest length of 435.0 feet. There is a total of 44gates in the Link River Dam and canal headworks structure, see appendix drawing A-1.

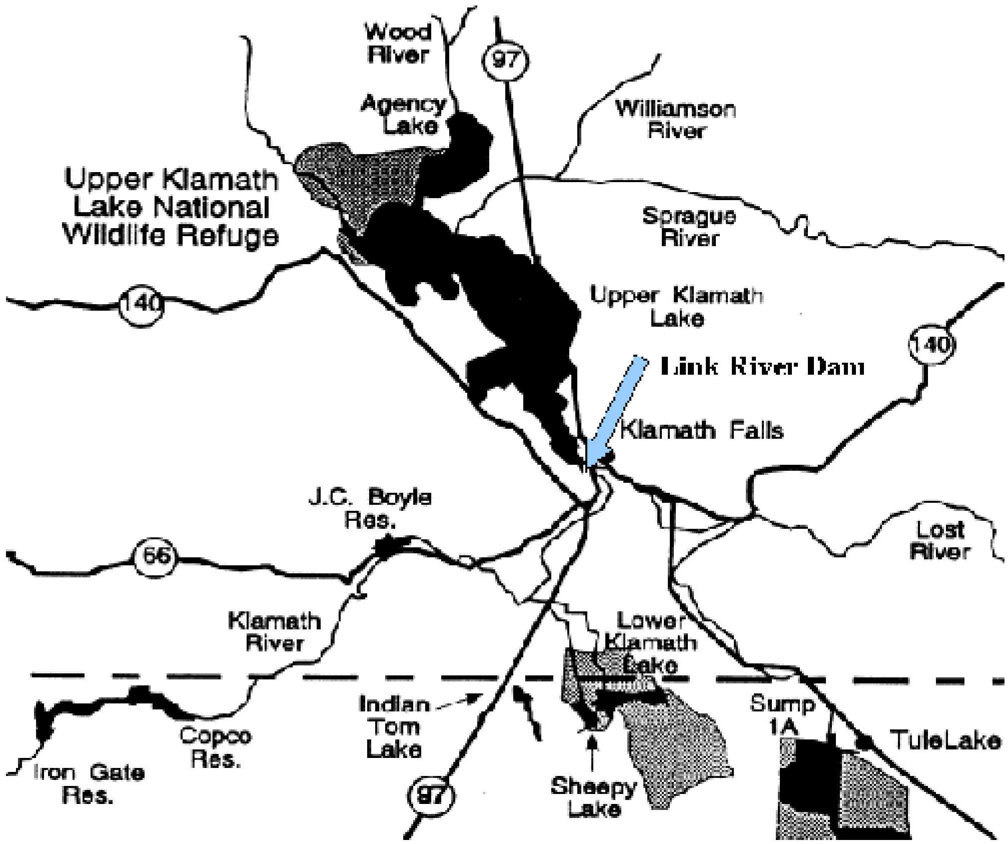


Figure 1 - Location of Link River Dam, Oregon.

Figure 2 - Link River Dam looking east from Keno Canal.

On the west abutment of the dam is the headworks for the Keno (West) Canal. This canal headworks consists of six gate bays, each bay with a 5.0-foot wide by 7.0-foot-high slide gate. The sill elevation of each gate bay is 4129 feet. The slide gates are operated by screw-lift hoists that are driven by an electric-motor driven chain-and-sprocket assembly, that is mounted on a gantry. The Keno Canal delivers water to the West Powerplant; the discharge from the west canal-outlet structure is limited to 290 ft^3/s by the capacity of the Keno Canal. Only two of the Keno Canal slide gates (the second and fourth gates from the right end of the dam) are routinely used to make releases into the canal.

East of the Keno Canal headworks are six river outlet gates. The river-outlet gate section consists of six bays, each with a 5.0-foot-wide by 7.0-foot high slidegate. The sill elevation of each gate is 4130 feet. The four gates on the right side of the river-outlet section are identical to the gates within the adjacent west canal outlet section, and are operated with the same gantry-mounted chain-and-sprocket assembly. The two left-most river-outlet gates have their own individual electric motor drive hoists. A stilling basin was constructed for the river-outlet section in 1952, see appendix figure A2. The design discharge capacity of the river-outlet section is 3,000 ft^3/s.

Continuing east across the dam are 24 stoplogged spillway bays numbered from west to east. A fish ladder occupies bay 24, the east most bay. Spillway bays are equipped with 8-foot-wide timber or concrete stoplogs. The 10 right-most spillway bays are equipped with steel-framed concrete panel stoplogs; the remaining spillway stoplogs are timber. The fish-ladder bay is not stoplogged. Stoplogs are removed and installed with an overhead monorail electric hoist and trolley. The crest elevation of each of the spillway bays is 4135 feet. The combined design discharge capacity of the spillway section is 13,000 ft^3/s. Only bays 1 through 10 are normally used to pass spillway flows.

The fish ladder that passes though spillway bay 24 was constructed in 1926, figure 3. The ladder is a pool and weir design originally constructed with 10 pools along its length, see appendix drawing A-3. Each weir was designed to provide about one foot of drop. In 1988 an additional pool was added at the downstream end to reduce an excessive water surface drop at the ladder entrance. The ladder is eight feet wide with weirs spaced eight feet apart. Weirs have four-feet long crests that can be stoplogged to adjust weir height. The fish ladder is laid out in an “L” shape that runs parallel to the spillway axis 25 feet downstream of spillway bays 17 through 24.

At the east (left) end of the dam is the headworks of the Ankeny (East) Canal, figure 4. The Ankeny canal-outlet headworks is composed of seven bays, each with a 5.0-foot-wide by 7.0-foot-high slide gate; each of the slide gates has its own electric-motor driven hoist. The Ankeny Canal headworks supplies water to a 12-foot diameter wood stave pipe that leads to the East Powerplant. The sill elevation of each gate bay is 4130 feet. The capacity of the pipe limits the discharge from the gate structure to 1,000 ft^3/s.

Figure 3 - View of existing Link River fishway.

Figure 4 - View of the Ankeny canal and headworks.

Major Fish Species of Concern (Perkins 2000) - Link river and Upper Klamath Lake support many fish species. Passage between Link River and Upper Klamath Lake is especially important for two native sucker species. The Lost River sucker *Deltistes luxatus* and shortnose sucker *Chasmistes brevirostris* are large, long-lived suckers endemic to the upper Klamath Basin of Oregon and California. Both species are typically lake dwelling but migrate to tributaries or shoreline springs to spawn. Once extremely abundant, both species have experienced severe population declines and were federally listed as endangered in 1988.

Shortnose Lake Sucker (FWS 1993) - Lakesuckers (genus *Chasmistes*) are differentiated from other members of the family Catostomidae by thin lips, the lobes of which are separated and may lack papillae, and by a large terminal, oblique mouth. The four recognized species are residents of three distinct drainage basins: cui-ui (*C. cujus*) in the Truckee River basin of western Nevada (Pyramid Lake); shortnose sucker (*C. brevirostris*) in the Klamath River basin of Oregon and California; June sucker (*C. liorus*) in Utah Lake; and the recently extinct Snake River sucker (*C. muriei*) of the upper Snake River in Wyoming.

The Lost River Sucker (FWS 1993) - The Lost River sucker was first classified as a member of genus *Chasmistes*. It was later reclassified into a new monotypic genus *Deltistes*. Lost River suckers are one of the largest sucker species growing to 3 ft in length. The Lost River sucker is distinguished by its long snout and a wide medium notch in the lower lip that has one or two large papillae between the notch and the edge of the lower lip.

Fish Passage Requirements at Link River Dam

Sucker passage - The shortnose sucker and Lost River sucker spawn in the spring. During spawning they move from the lake into tributaries or lake areas where springs are found. There is no evidence suckers migrate downstream into Link River during spawning. Upstream passage for suckers is primarily needed to allow fish access back to Upper Klamath Lake should they be carried downstream in spillway, outlet works or diversion flows. Three large water diversions are located on Upper Klamath Lake near the dam. The Keno and Ankeny power canals divert water adjacent to the dam. Both canals are unscreened and carry water to hydro-power plants located about one mile downstream. Fish survival after passing through the power plants is not well documented. However, both powerplants are low head facilities and likely pass significant numbers of entrained fish uninjured. Power plant flows reenter Link River near the confluence of Link River and Lake Ewauna. Fish carried downstream by power plant diversions must move upstream past Klamath Falls and Link River Dam to reenter Upper Klamath Lake.

Reclamation's A-Canal is located about 2,500 ft up-lake from the dam. The A-Canal diverts about 1,150 ft^3/s for irrigation. The canal is currently unscreened, however construction of fish screens in the canal is planned in the near future. Preliminary fish screen designs include an in-canal fish screen and fish bypass to the river downstream of Link River Dam. For this screen concept, lake resident fish entrained in the canal would be screened and reintroduced into Link River below the dam.

Rainbow Trout Passage - Passage for rainbow trout is also important at the dam. Trout migrate from Link River to Upper Klamath Lake in the fall when water temperatures drop.

Fishway Options

Power canals located on either abutment of the dam restrict fish passage alternatives to those that can pass through the dam. The types of fishpasses considered in the concept study were: flumes with vertical slot style baffles, flumes with denil style baffles, fish locks and fish trap/lift systems. Natural style rock fishways were not considered due to site constrictions and flumes with orifice or weir style baffles were not considered due to Fish and Wildlife Service experience with poor cui-ui passage through similar fishways. Fish locks and fish traps/lift systems were dropped from concept design because, compared to baffle fishways, the greater complexity and higher operation and maintenance costs of this type of passage system were not warranted for a low head dam.

Vertical Slot Fishway - A vertical slot fishway uses a series of baffles with vertical slots in each baffle, figure 5. The baffles are designed to create backwater pools between baffles and higher velocity flow through the baffle slots. The vertical slots allow passage at nearly all depths within the water column and can operate over a relatively large range of flows and river stage.

Denil Fishway - A Denil fishway uses closely spaced baffles to create strong turbulence and rapid energy dissipation to control flow velocity, figure 6. At a given depth, flow velocity is nearly constant along the chute while varying sharply with depth. Lowest velocities occur near the chute invert. The Denil design requires fish pass by swimming the length of the chute in a single burst. For long ladders, intermediate resting areas are used.

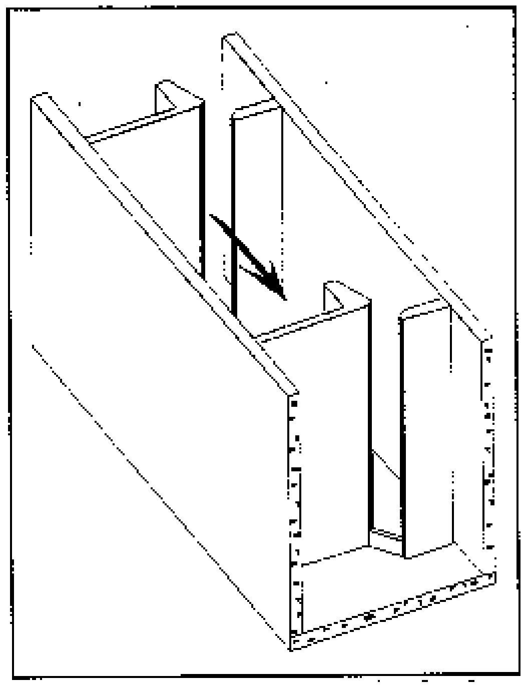


Figure 5 - Vertical slot baffled fishway, FWS, 1997.

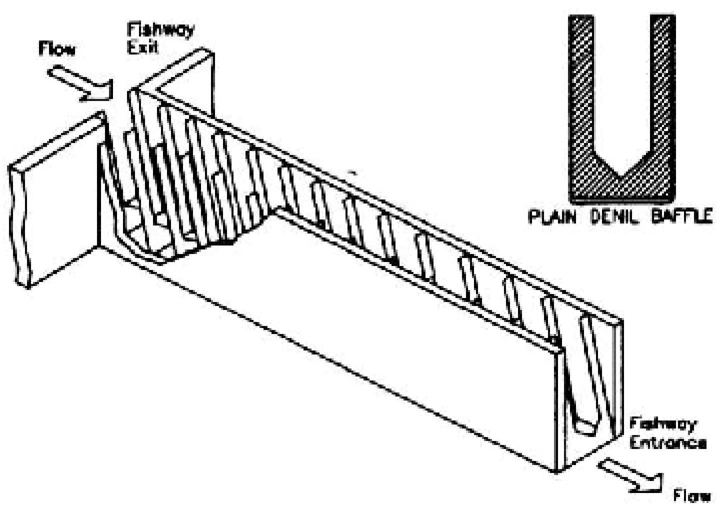


Figure 6 - Schematic of a Ďenil Fishway, FWS 1997.

Experience with Sucker Passage Through Baffled Fishways

Chiloquin Dam Fishway - Chiloquin Dam is located on the Sprague River near Chiloquin, Oregon. The dam creates about 10 ft of hydraulic head. An orifice and pool fishway is located on the right bank. The fishway has a 1:10 slope with nine pools. The original fishway was constructed with weir baffles which were found to be ineffective for passing Lost River and shortnose suckers. Weirs were replaced with baffles containing 12 inch by 16 inch orifices located about one foot below the surface. Each orifice creates a water surface change of about 1.1 ft with average passage velocities of about 6 ft/s. From the mid-1960's to the early 1980's Lost River and shortnose suckers were documented moving through the fishway (FWS Recovery Plan, 1993). However, the fishway is not thought to provide effective sucker passage. There are observations of fish moving into the ladder and dropping back (CH2M-Hill, 1996) and accounts of the ladder being a favorite spot of tribal members when snag fishery existed. A new vertical slot ladder at a 1:20 slope was proposed for the dam in 1996.

Pyramid Lake Fishway - Significant experience with lake sucker passage has been gained at Marble Bluff Dam, near Reno, Nevada. U.S. Fish and Wildlife Service (FWS), Reclamation and the Pyramid Lake Paiute Nation have worked with passage of cui-ui lake suckers since the early 1970's, Mefford 1998. Cui-ui migrate from Pyramid Lake upstream into the lower Truckee River to spawn in the spring. In 1970 Marble Bluff Dam was constructed to halt severe degredation of the Truckee River above Pyramid Lake. In conjunction with constructing the dam a 3 mile long fishway channel with a series of five weir and orifice style fish ladders was constructed for upstream passage. The fishway design was based on then-typical salmonid style fishways and available biological studies (Koch 1972, 1973, 1976; Ringo and Sonnevil 1977) of the cui-ui physical attributes. The baffled fishways were constructed on a 10 percent slope with combination weir/orifice baffles spaced every 10 ft of run, figure 7. The original water surface drop over each baffle was one foot. The fish ladders quickly proved to be nearly total barriers to cui-ui passage. Cui-ui which are bottom oriented fish native to lakes and low gradient stream environments failed to negotiate flow over weirs. Many cui-ui entering the fishway ladders stayed near the bottom avoiding the strong vertical turbulence of flow plunging over the weirs. Intermediate baffle walls were installed to reduce the

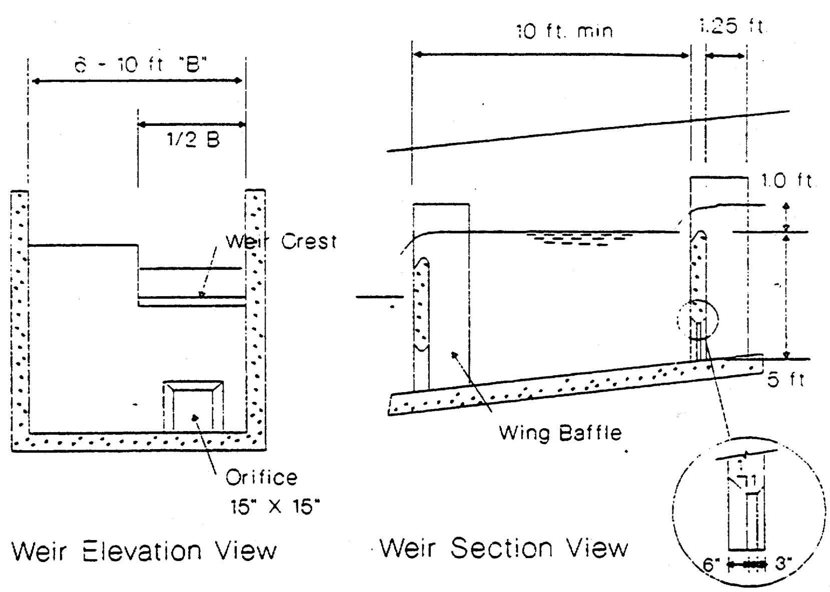


Figure 7 - Schematic of a Half-Ice Harbor fishway design, FWS 1997.

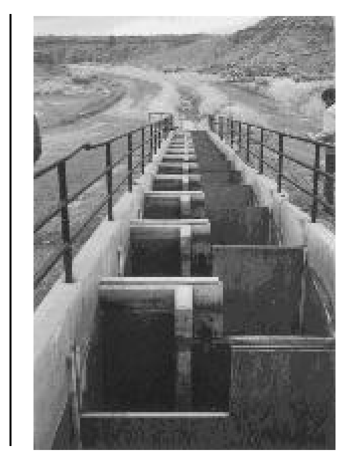


Figure 8 - Pyramid Lake fishway ladder. Shown, with temporary intermediate baffles.

water surface drop per pool to 0.5 feet, figure 8. Cui-ui passage improved; however crowding of weaker swimmers at ladder entrances continued to be a major problem. Fish and Wildlife Service sampling of fish that passed the ladders found a high percentage were young male cui-ui. This data indicated the pool and weir ladders were creating a degree of selective passage based on age and sex.

Pyramid Lake Fishway Exit Ladder - In 1995, Reclamation working with FWS, started investigating fish ladder designs for improving cui-ui passage. A number of ladder baffle designs and gradients were studied using laboratory models and numeric simulations. The design objectives for the project were; hold passage water velocity to about 4.5 ft/s and design baffles that maximize downstream flow within pools between baffles. Maximizing downstream flow in fishway pools resulted from field observations that indicated cui-ui tend to school densely and hold for long periods in large horizontal eddies. Holding may be due to fish disorientation due to poor visibility in turbid water coupled with the complex velocity field within a large eddy. The Pyramid Lake fishway exit ladder was replaced with a unique dual vertical slot baffle design in 1998. The fishway is 8 ft wide, 6 ft deep, with baffles placed every 8 ft of length, figure 9. The fishway gradient is 3.1 percent. Dual-slot-chevron shaped baffles were designed to maximize upstream passage attraction between baffles.

Figure 9 - Pyramid Lake Fishway exit ladder designed with chevron shaped vertical slot baffles (looking downstream).

Numana Fishway - The Numana Dam fishway, figure 10, is located on the Truckee River about 10 miles upstream of Pyramid Lake. The fishway is a typical vertical slot baffle design. The Numana fishway provides about 10 ft of elevation rise at a 5-percent slope with about 0.5 ft of drop per baffle. In 1998, FWS estimated about 60,000 cui-ui passed through the fishway. However, observations of fish crowding below the dam and in the fishway suggest many cui-ui are significantly delayed or prevented from passing the dam each year.

Figure 10 - View of Numana Dam vertical slot fishway.

Redlands Fishway - Redlands Fishway is located adjacent to Redlands Diversion Dam on the Gunnison River near Grand Junction, Colorado. The fishway was constructed to assist in the recovery of Colorado pikeminnow (Ptychocheilus lucius) and razorback suckers (Xyrauchen texanus) native to the Colorado River system. The fishway was designed on a 3.75 percent grade with vertical slot and orifice baffles spaced every 6 ft, figure 11. The total elevation difference across the ladder is about 10 ft. The ladder has been operating since 1996. A fish trap is operated at the top of the fishway to monitor fish passage and control upstream passage of some non-native species. Trap results from 1996 through 1998 show between 7,000 and 11,500 native fish including bluehead suckers (Catostomus discobolus), flannel mouth suckers (Catostomus latipinnis), roundtail chub (Gila robusta) and Colorado pikeminnow passed through the fishway each year (Burdick,1999). The predominant fish species passing through the fishway have been bluehead and flannel mouth suckers.

Figure 11 - View of the Redlands Fishway (looking downstream).

Fairford and Cowan Lake Fishways - Prototype studies of two Denil ladders on the Fairford River, Manitoba and Cowan Lake, Saskatchewan (Katopodis et al.,1991) found the ladders provided effective passage for sauger, walleys, white suckers, and other resident fish spieces. The Denil ladders at Fairford and Cowan slope at 12% with run lengths of between 15 and 30 ft, figure 12. The ladders have a total elevation drop of about 7 ft. At Fairford, velocities in the weir chutes varied from about 4.5 ft/s at 0.6 depth to about 2.3 ft/s at 0.2 depth. Slightly higher velocities were measured at Cowan. The velocities are above reported sustained swimming velocities of many species using the ladders. However, velocities were below burst swimming speeds. Weak swimmers were assumed to pass up the Denil ladders by holding close to the bottom in the lowest velocity zone. Nearly all documented fish using the ladders were adults. Katapodis's study did not compare ladder usage to downstream fish populations. Therefore, the study results do not clearly show the overall effectiveness of the ladders. A previous Canadian study by Schwalme and Mackay (1985), of two Denil ladders and a vertical slot ladder found similar results to Katopodis's. The Schwalme and Mackay study also found juveniles and weaker swimmers appeared to prefer the vertical slot ladder.

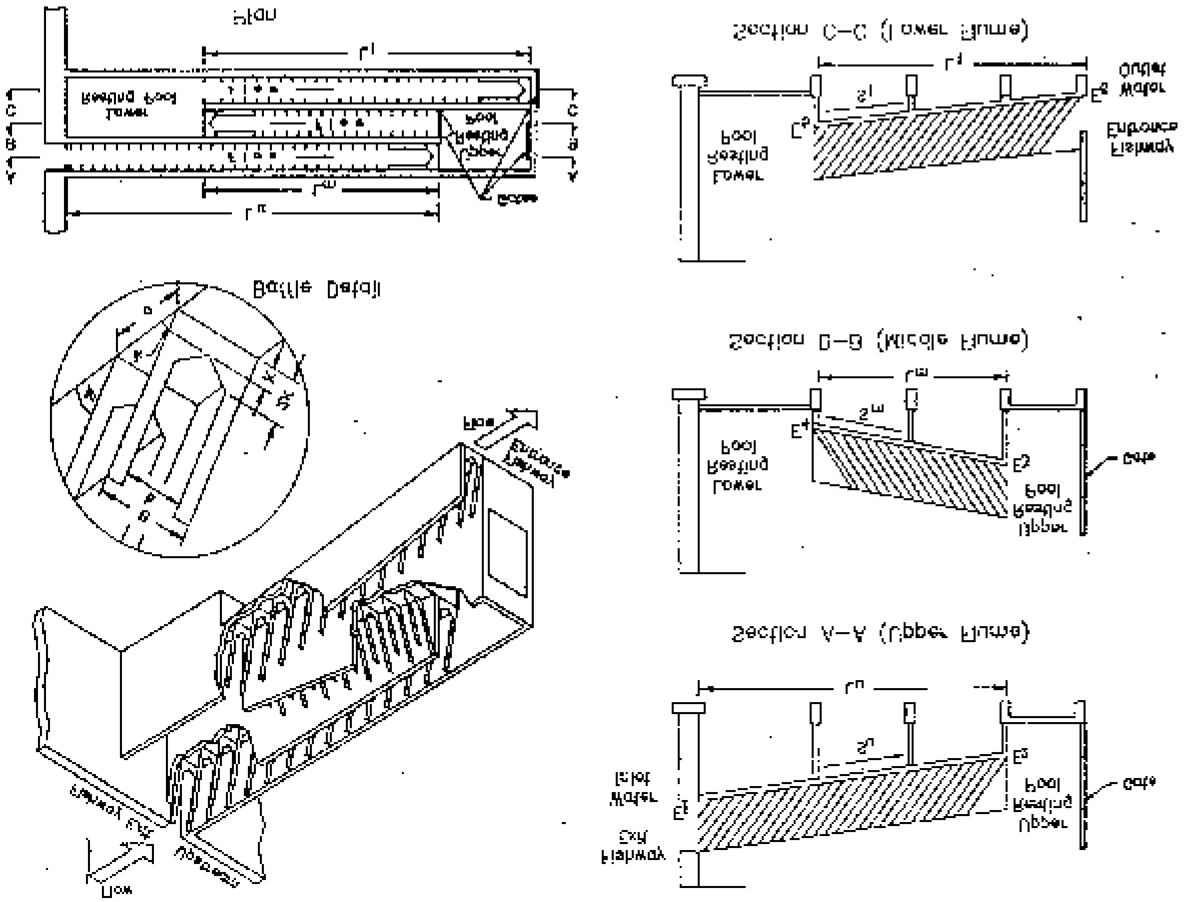


Figure 12 - Fairfield Denil fishway, Katapodis 1991.

WRRL Laboratory Tests - In 1998, a limited series of sucker passage tests were conducted in the Water Resources Research Laboratory using a Denil fishway set at a 5 percent slope. The laboratory flume tests investigated passage of 6 to 8 inch long razorback suckers through a 20 ft long Denil fishway. Observations of fish attempting to pass through the Denil fishway revealed passage was accompanied by a high rate of fall back within the fishway. Most suckers attempted to pass up the Denil fishway staying close to the fishway invert. Many of the fish observed became entrained in the strong vertical eddies that form near the floor behind each baffle. These fish would then loss swimming orientation and tumbled back down the fishway.

Previous Link River Dam Fish Passage Studies

Pacific Power and Light Company commissioned Link River Dam fish passage concept studies in 1986 (Orsborn) and 1990 (Ott). Both studies identify many problems with the existing pool and weir fish ladder. The main problems cited are poor attraction conditions and ladder hydraulics. Poor attraction conditions are largely caused by the ladders left bank location. To find the entrance of the existing ladder requires fish leave the main outlet works flow and follow what is referred to as the downstream cross channel toward the left abutment. The cross channel is an excavated channel that runs parallel to the dam downstream of the spillway gates. Fishway discharge flows behind the spillway gates to the left outlet works stilling basin wall then downstream to the main river channel. During non-spillway flows, only gate leakage and fishway flows (normally < 10 ft^3/s) provide attraction to the existing fishway entrance. During spillway operation high velocity jets issuing from the spillway gates into the cross channel impede attraction. Spillway operation creates a highly turbulent and chaotic flow condition in the cross channel.

The existing fish ladder is a weir and pool design with a horizontal bottom. Weirs control the fishway hydraulic slope. Weirs are the highest at the upstream end and successively decrease in one foot steps. The height of the fishway weirs must be manually adjusted to accommodate changes in lake and tailwater levels to maintain uniform flow conditions across each weir. If weirs are not properly adjusted for lake and tailwater elevations, the water surface drop through the entrance weir can be much greater than the upstream weirs. For example, Ott cites fishway pool elevations measured during a 1989 survey of the ladder. The survey shows a water surface drop of 2.0 ft across the entrance weir with less than one foot drop for upstream weirs. This flow pattern occurs whenever the fishway entrance depth is less than the exit depth.

The Osborn study proposed several modifications for the existing fishway and cross channel to improve attraction and passage. The main recommendations were:

1. The lower cross channel outlet should be revised with a concrete weir and slot structure to provide better attraction.
2. A removable, diagonal, barrier should be installed upstream of the fishway entrance to keep fish from swimming upstream of the fishway entrance.
3. The entrance to the fishway should be reconstructed with two chambers and a slotted entrance to improve attraction over a wide range of flows.
4. The fishway should be modified to a series of three Denil fishway sections within the existing structure, (see appendix figure A3).

The Ott Engineering study presents on two alternatives for modifying the existing fishway and reference to other alternatives that require the construction of new fishways. The main fishway alternatives proposed are:

1. Modify the existing ladder weirs to vertical slot baffles and reduce the water surface elevation of the existing fishway by using the cross channel as part of the ladder. The proposal adds five slotted baffles and pools along the cross channel, (see appendix figure A4). The baffles would each provide a water surface drop of about 0.8 ft.
2. Reconstruct the existing fishway to a vertical slot fishway. Lengthen the fishway by adding six additional pools downstream of the existing fishway entrance, (see appendix figure A5). Similar to Alternative 1, the baffles would each provide a water surface drop of about 0.8 ft.

Link River Dam Hydraulics

<u>Upper Klamath Lake</u> - The top of active conservation for Upper Klamath Lake is elevation 4143.3 feet. Average, minimum and maximum lake elevation for Upper Klamath Lake based on monthly data for the

years 1921 to 2000 are given in figure 13. Lake elevations typically peak in March and April then drop through October . On average lake elevations decline about 2.5 ft from March through October. The maximum decline of lake elevation recorded during the March through October period was 5.8 ft. Figure 14 shows monthly lake elevation data in percent exceedance. There is a 95 percent probability that lake elevation will be between elevation 4138.0 and 4143.3 during the main fish migration period of March through November.

Link River Flow - Link River flows are totally derived from releases from Link River Dam. Daily average river flow for the period September 1989 through September 1999 is given in figure 15. River flow was calculated by subtracting daily East Canal flows provided by Pacificorp from flow measured at US Geological Survey river gauge 11507500. The data plotted is considered approximate. Figure 15 shows outlet works releases increased from about mid-1994 to 1999 over the previous 5 years. Pacificorp indicated higher outlet works flows in recent years were due to changes in dam operation to increase fishery flows below the dam (personal communication). Figure 16 gives calculated river flow data in percent exceedance for the yearly period of March through November. For the ten year period of record, flow through the river outlets occurred about 60 percent of the time and 49 percent of the time exceeded 100 ft^3/s. River outlet flows from 1995 to 1999 were significantly higher than the previous five years. Outlet flow occurred about 88 percent of the time and 82 percent of the time exceeded 100 ft^3/s. During both the 1989-1999 and 1995-1999 periods five percent of the time flows exceeded outlet works capacity (3,000 ft^3/s).

Tailwater Elevation at the Dam - Tailwater data is not available for the area just downstream of the dam. The only tailwater data available is presented by Ott (1990). Ott cites the tailwater elevation at the end of the outlet works training wall as 4130.5 with gates closed, minimal gate leakage and the fishway operating. He made observations of highwater marks left by then recent high flows and estimated the tailwater rises below the dam about six to eight feet for a flow of 4,000 ft^3/s. For the purposes of this concept report, the tailwater elevation for 100 ft^3/s river flow was estimated by assuming the river immediately downstream of the outlet stilling basin acts like a broad crested weir with a crest length of about 50 ft. This approach gives an estimated tailwater elevation 0.75 ft above the gates closed condition given by Ott. Herein the tailwater elevation for a flow of 3,000 ft^3/s is assumed to be 6 ft higher than the gates closed elevation. Therefore, tailwater elevations at the outlet works training wall for flows of 100 ft^3/s and 3,000 ft^3/s are estimated as 4131.5 and 4136.5, respectively.

Operating procedure for flow releases - Flow is normally released through the outlet works. When flow release requirements exceed outlet works capacity, spillway gates are progressively opened starting adjacent to the outlet works and proceeding toward the left bank.

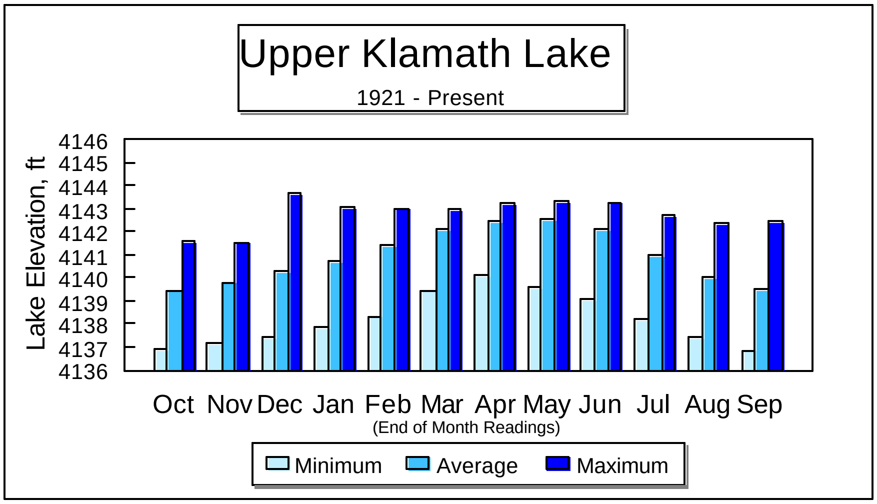


Figure 13 - Monthly minimum, average and maximum lake elevation based on historic data.

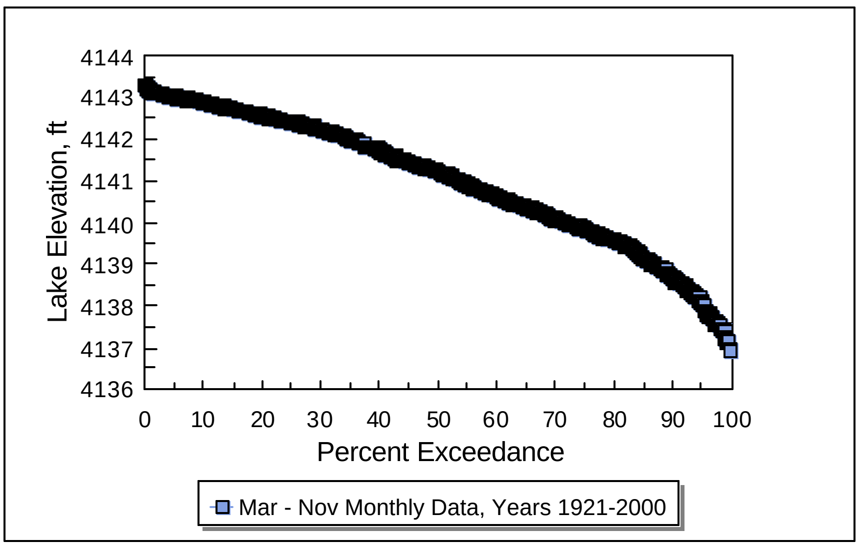


Figure 14 - Klamath Lake Elevation data in percent exceedance.

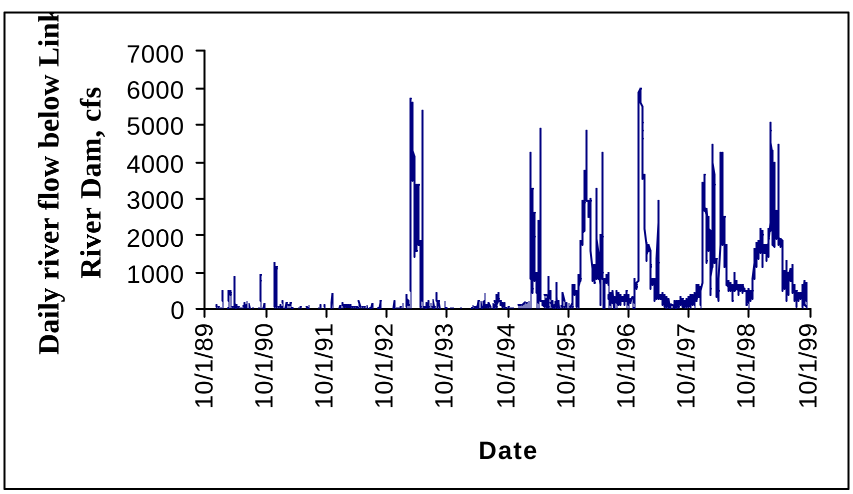


Figure 15 - Daily river flow below Link River Dam.

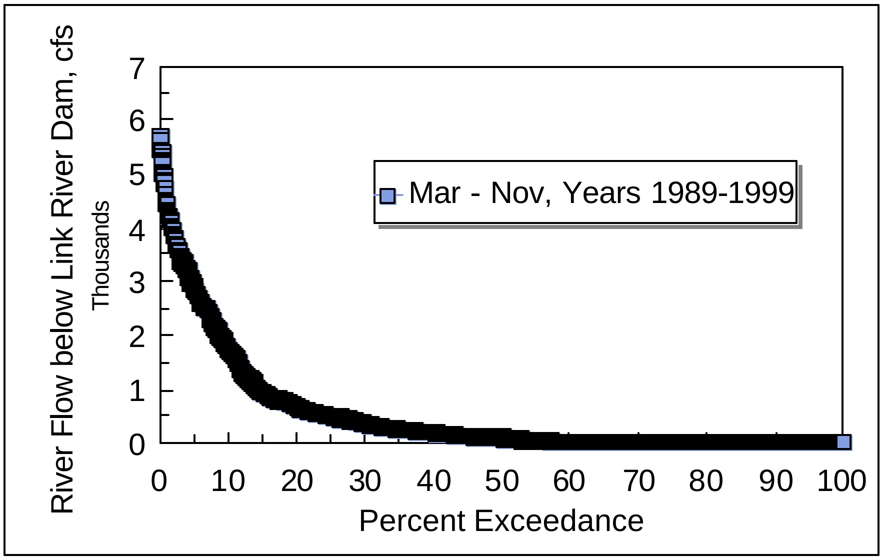


Figure 16 - River flow below Link River Dam in percent exceedance.

Summary of Fishway Hydraulic Design Conditions

Table 1 - Fishway hydraulic design limits (local USBR datum, for NAV 88 add 2.2 ft)

	Lake Elevation, ft	Tailwater Elevation, ft	River Flow, ft^3/s
Maximum	4143.3	4136.5	3,000.0
Minimum	4138.0	4131.25	100.0

Based on these conditions a maximum difference in hydraulic height of 12 ft occurs for maximum reservoir and minimum flow release for passage. The range of lake elevation and tailwater elevation for fishway design are 5.3 ft and 5.25.0 ft, respectively. Figure 17 gives 1989 through 1999 historic data for Link River flow and Klamath Lake elevation. The data shows low river releases frequently occurred at high lake elevations. Also during the period, when lake elevations were below 4140 river releases were usually less than 1,000 ft^3/s.

Design objectives for the fishway used for the concept study are based largely on experience with passage of lake sucker species and other river suckers in the western United States. Options for a new Link River Dam Fishway were considered that provide for:

?A differential head range between the entrance and exit of between 12 ft and 6.0 ft,
? a minimum fishway depth of 2 ft,
? a minimum fishway attraction velocity of 1 ft/s,
? flow depth fluctuations of up to 5.3 ft above minimum,
? fish passage at any flow depth,
? a maximum passage velocity of 5.0 ft/s and
? strong attraction flows to the fishway entrance.

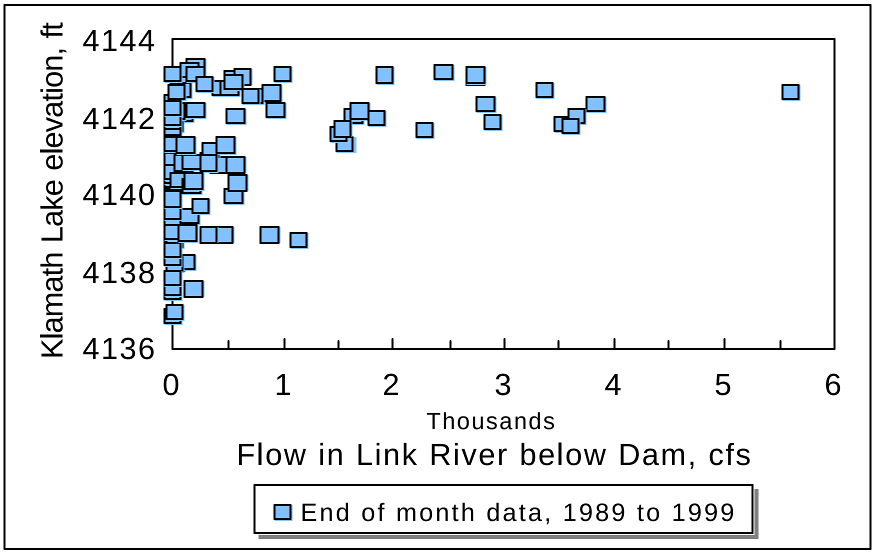


Figure 17 - Klamath Lake elevation versus Link River flow for the years 1989 to 1999.

Fishway Alternatives

Fish passage experiences at Chiloquin Dam, Marble Bluff Dam, Numana Dam, Redlands Dam and the WRRL indicate a general trend of declining sucker passage efficiency as ladder slope, flow velocity and flow turbulence increase. Based on these case studies three fishway alternatives were developed for Link River Dam. All proposed alternatives are similar in hydraulic design. A vertical slot fishway design is proposed consisting of a chute sloping at 4.75 percent containing 33 vertical slot baffles designed for a water surface drop of 0.36 ft per baffle. A comparison of hydraulic design parameters to those of other fishways referenced in the study are summarized in Table 2. The proposed design would provide passage velocities about 0.8 ft/s lower than Numana Fishway and about 0.3 ft/s greater than the new Pyramid Lake exit ladder.

Table 2 - Comparison of proposed fishway hydraulic design to other fishways where sucker species are present.

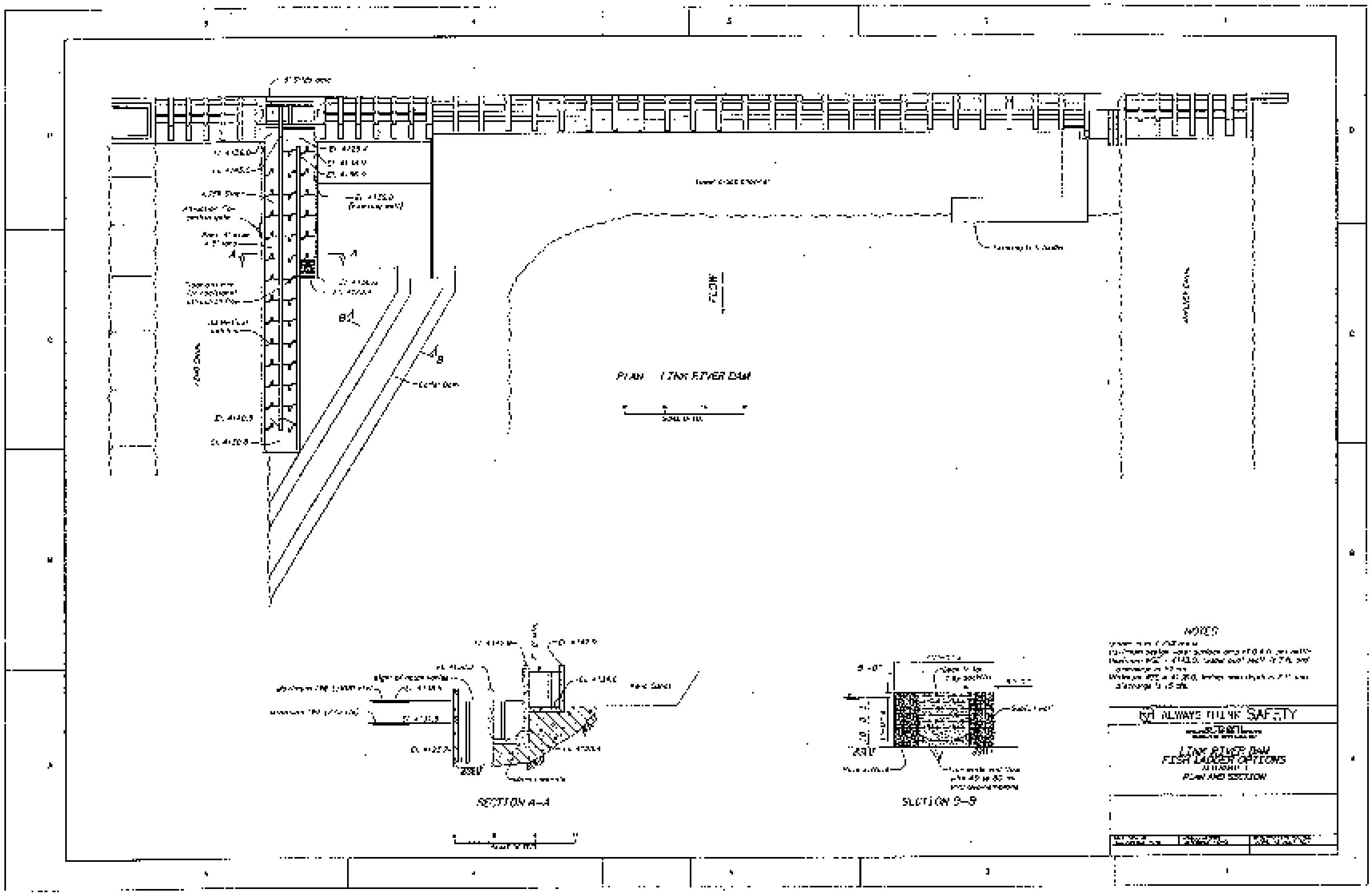
Fishway	Location	Sucker species present	Baffle type	WS drop per baffle, (ft)	Peak velocity across baffle, (ft/s)	Channel slope, (%)
Proposed design	Link River	Lost river and short nose suckers	Vertical slot single or dual	0.36	4.8	4.75
Chiloquin Dam	Lost River Oregon	Lost river and short nose suckers	12"x16" orifice 1 foot below water surface	1.1	8.4	10.0
Pyramid Lake (modified with intermediate baffles)	Truckee River, Nv	Cui-ui	Weir and pool	0.5	5.7	10.0

Numana	Truckee River, Nv	Cui-ui	Vertical slot	0.5	5.6	5.0
Pyramid Lake (Exit ladder)	Truckee River, Nv	Cui-ui	Vertical dual slot chevron shape	0.3	4.5	3.1
Redlands	Gunnison River, Co.	Razorback, bluehead and flannel mouth suckers	Vertical slot	0.23	3.8	3.75
Fairford and Cowan Lake Fishways	Fairfield River Manitoba, Canada	White suckers	Denil	NA	(Measured Vel.) 4.5 at .6 depth, and 2.3 at .2 depth	12.0

Single or dual vertical slot fishway baffle designs similar to Redlands or the Pyramid Lake fishway exit ladder could be used in each fishway alternative presented. The fishway concept alternatives developed vary mainly in location and need for supplemental attraction flow. When ever possible, locating a fishway entrance adjacent to a dam's main flow release structure is preferred. The old saying "go with the flow" is especially true for upstream migrating fish. Studies by Pavlov, (1989) indicates fish move upstream seeking flow at a velocity of between 0.6 and 0.8 times their maximum cruising velocity. If flow velocity is lower than about 0.3 times the fish's cruising speed, fish lose orientation to the flow direction and often hold or drift downstream. Based on studies of cui-ui by Ringo and Sonnevil (1977) and Koch and Contreras (1972) the maximum cruising speed of cui-ui is about 4 to 5 ft/s. A similar velocity range is assumed for the Lost River and shortnose sucker. Following Pavlov's study, attraction flow velocity for lake suckers should be between about 1.0 to 3.0 ft/s. This criteria was followed in selecting fishway location. This concept study presents two fishway concepts located adjacent to the river outlet works and an east bank fishway. Fishway concepts located adjacent to the river outlets offer the best attraction flow conditions while the east bank fishway offers the least effect on existing structures, but will require larger auxiliary attraction flow releases. All fishway designs present in this report are concept level. Prior to final design, additional field data needs to be collected on the Link River Dam and tailwater elevation versus Link River flow releases.

<u>Alternative No.1</u> - A west bank ladder is proposed lying between the Keno Canal and the outlet works stilling basin guide wall, figure 18. The fishway exit would penetrate the dam between the Keno Canal headworks and the outlet works, figure 19. The fishway would slope at about 4.75 percent with 33 six-ft-wide by eight-ft-long pools separated by vertical slot baffles. A water surface change of about 0.36 ft would occur across each baffle for lake elevation 4143.3 and a downstream river flow of 275 ft^3/s. During periods of large river releases, auxiliary attraction flow would be supplied through floor diffusers near the fishway entrance to maintain a minimum attraction velocity of 1.0 ft/s. To minimize the risk of re-entrainment of fish exiting the fishway the canal gate adjacent to the fishway exit would be closed during normal operation.

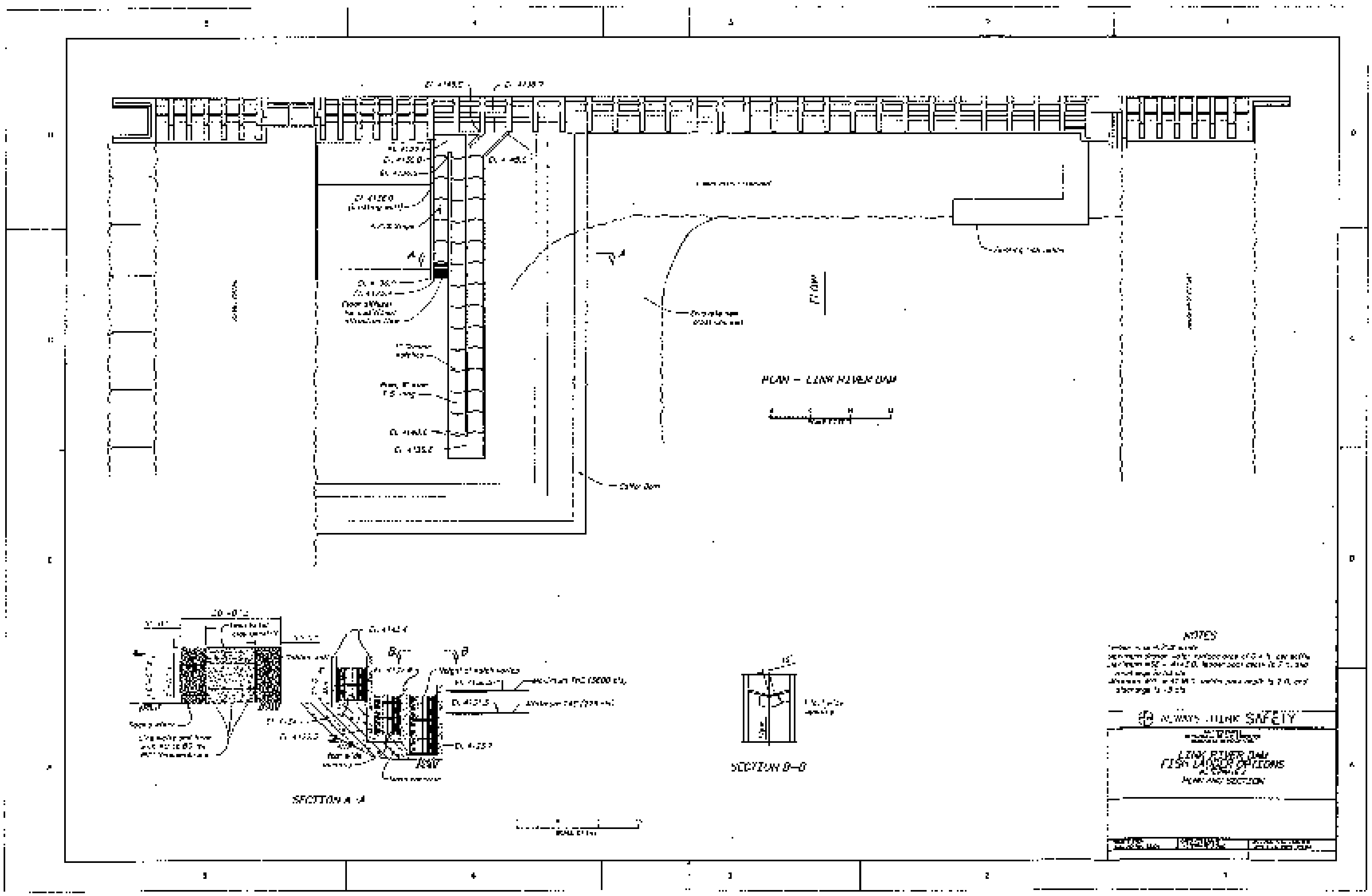
Figure 18 - View looking upstream at Keno Canal and the west outlet works stilling basin wall.



FLOW
SECTION A–A
SECTION B–B
NOTES
ALWAYS THINK SAFETY
FISH LADDER OPTIONS
PLAN AND SECTION

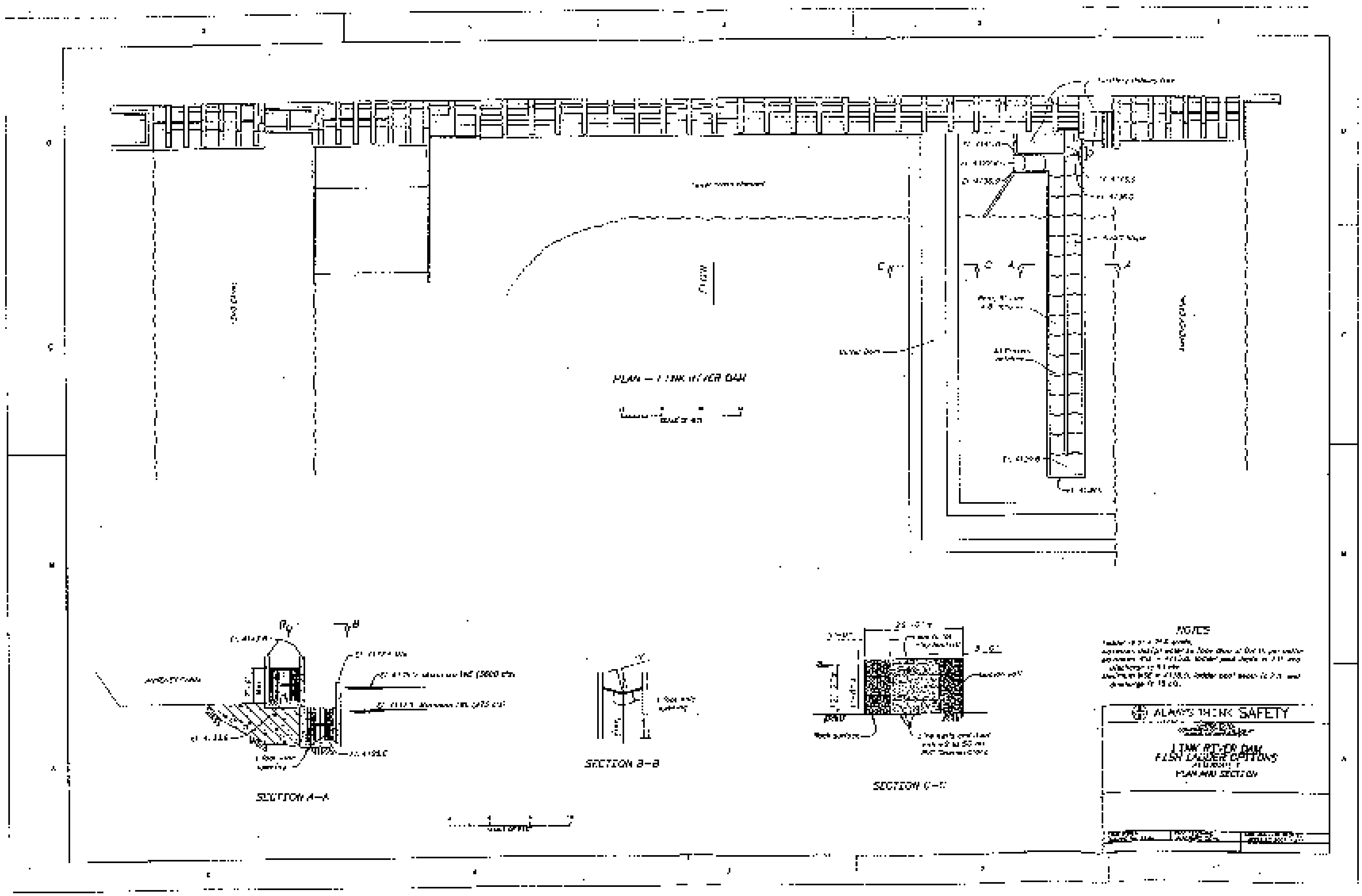
<u>Alternative No.2</u> - Alternative No. 2 places the fishway ladder adjacent to the east wall of the outlet works stilling basin, figure 20. The fishway would exit through an existing spillway gate opening. The fishway would slope at about 4.75 percent with 33 six-ft-wide by eight-ft-long pools separated by vertical slot baffles, figure 21. A water surface change of about 0.36 ft would occur across each baffle for lake elevation 4143.3 and a downstream river flow of 275 ft^3/s. During periods of large river releases, auxiliary attraction flow would be supplied through floor diffusers near the fishway entrance to maintain a minimum attraction velocity of 1.0 ft/s. This concept would require spillway gates 1, 2 and 3 be removed from service. Operation of gate four would increase the risk of fish re-entrainment and would only be operated when necessary to pass flood flows.

Figure 20 - View looking downstream along the east wall of the outlet works stilling basin.


PLAN – LINK RIVER DAM
FLOW
Coffer Dam
SECTION A–A
SECTION B–B
NOTES
ALWAYS THINK SAFETY
LINK RIVER DAM
FISH LADDER OPTIONS
PLAN AND SECTION

Alternative No.3 - Construction of a east bank ladder is proposed adjacent to the Ankeny Canal, figure 22. The proposed fishway would use the existing fishway exit. The fishway would slope at about 4.75 percent with 33 six-ft-wide by eight-ft-long pools separated by vertical slot baffles, figure 23. A water surface change of about 0.36 ft would occur across each baffle for lake elevation 4143.3 and a downstream river flow of 275 ft^3/s. Auxiliary attraction flow would be required to increase flow velocity in the cross channel to about 1 ft/s minimum. Three options for attraction flow are possible. First, an existing spillway bulkhead gate located near the fishway exit could be replaced with a bulkhead and 30 inch gate valve. Second, a 30 inch pipe and gated flow control structure could be constructed to provide water from the Ankeny Canal downstream of the headworks. Third, the A-Canal fish bypass could enter the river adjacent to the fishway entrance. This option for increasing fishway attraction flow is similar to Fish Screen Bypass Option 2 presented in the A-Canal fish screening feasibility report, (Montgomery Watson, 2001). This option would require larger attraction flow releases than Alternatives 1 or 2, but would not effect operation of the dam or diversion canals. Fishway attraction would be poor during spillway operation.

Figure 22 - View looking west along the cross channel from the existing fishway.


SECTION A—A
SECTION B—B
NOTES
ALWAYS THINK SAFETY
FISH LADDER OPTIONS

Fishway Construction

Alternative No.1 - Several site conditions effect construction of a west bank fishway at Link River Dam. First, construction access is restricted by the power canals that divert flow on each abutment and run p arallel to the river channel. The Keno Canal lies adjacent to the proposed fishway. Fishway construction would likely require shutting down the canal during the construction period. Construction access would be achieved from the west abutment across the canal. The dam is constructed on a large rock outcropping that forms Klamath Falls. Exposed surface rock extends well upstream and downstream of the dam. The exposed foundation rock requires site dewatering be achieved by constructing an earth cofferdam. An earth and rock gabion structure with a membrane lining is proposed from the east wall of the outlet works stilling basin to the Keno canal, see figure 19. River flows would be passed downstream using the spillway gates. Coffer damming upstream of the dam was assumed not necessary to penetrate the dam at the fishway exit. This assumption would be reviewed following collection of additional field data.

Alternative No.2 - Construction access would be from the west abutment. Depending on cost, the Keno Canal could be shut down or temporary bridging installed during fishway construction. Bridging the canal is assumed in the concept level cost estimate. The cost of shutting off the canal was not estimated for this study. Dewatering would require constructing a coffer dam from spillway bays five and six downstream and across the river, see figure 22. An earth and rock gabion coffer dam similar to Alternative 1 is proposed. River flows would be released using spillway gates seven through 10. No upstream coffer dam is necessary. Spillway gate No. 3 would be used as a bulk head during construction. Following fishway construction, gate hoists one, two and three could be removed and placed in spillway bays 11, 12 and 13. The new fishway would require rock excavation downstream of spillway gates four, five and six to re-established a channel between the downstream cross channel and the low river channel.

Alternative No.3 - Construction access would be from the east abutment. Access would have to be provided across the Ankeny Canal and a temporary road constructed downstream of the cross channel. Bridging the canal to provide construction access is assumed in the concept level cost estimate. A cost evaluation of shutting down the canal or bridging was not conducted. Dewatering would require constructing a coffer dam from Spillway Bay 18 to the Ankeny canal downstream of the proposed fishladder, see figure 23. An earth and rock gabion coffer dam similar to Alternative 1 is proposed. During construction river flows would be released using the outlet works. Spillway gates 1 through 10 could be used if required. No upstream coffer dam is assumed necessary.

Construction Period - Figure 24 gives the occurrence of historic river flows that exceeded a total flow of 3,000 ft^3/s at the Link River USGS gage for the years from 1969 to 1988. During this period river flows exceeded the capacity of the river outlets in most years requiring spillway gates to be opened. Link River Dam releases for the years 1989 to 1999 versus time of year given in figure 25 show lowest river flows occur from July through August. Figure 26 presents July through August flow data in percent exceedance. During this period, river flow releases occurred about 50 percent of the time and exceeded 1000 ft^3/s less than one percent of the time.

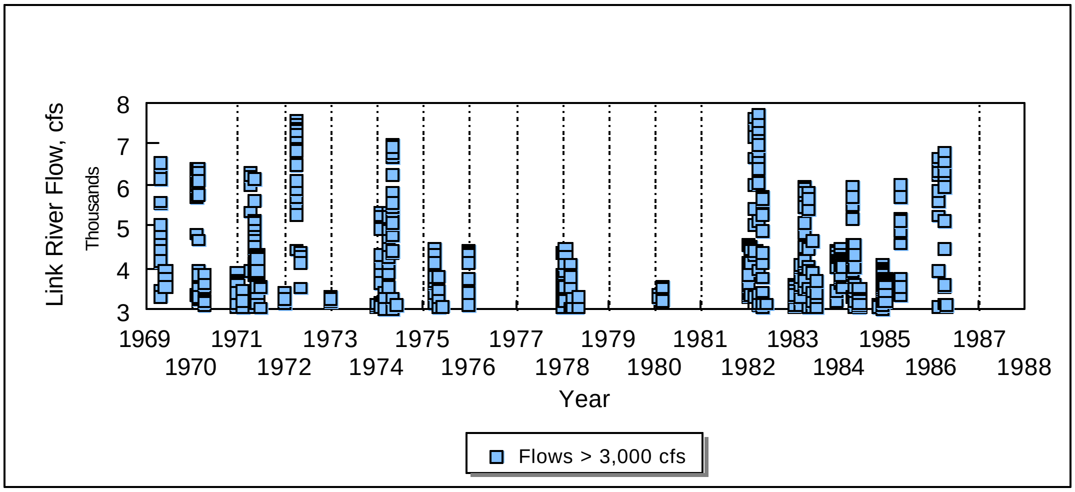


Figure 24 - River flows requiring operation of Link River Dam spillway bays during the period 1969 to 1988.

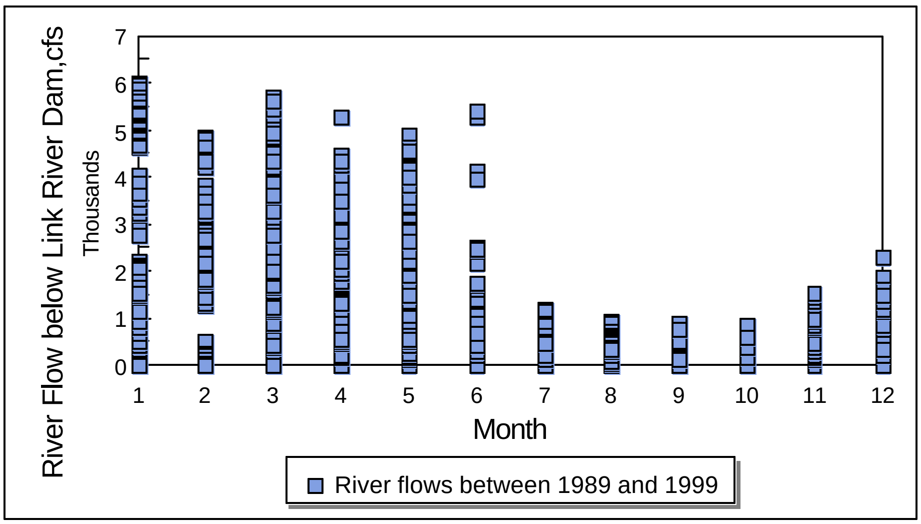


Figure 25 - Link River flows by month for the period 1989 to 1999.

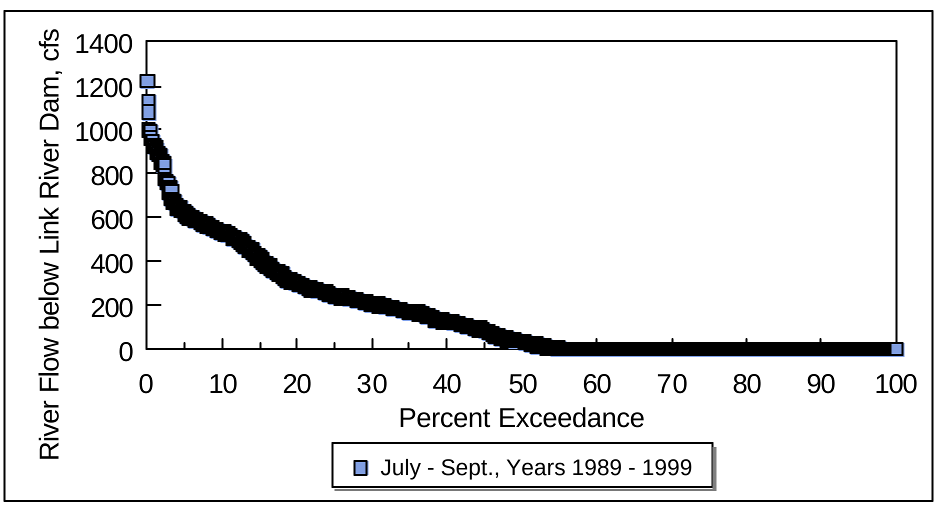


Figure 26 - Link river flow percent exceedance for the months July through August, 1989 to 1999.

Construction Cost Estimates

Concept level cost estimates for each fishway alternative are given in tables 2-4. The estimates are based on limited available data of existing structures and site conditions. The estimated cost of Alternative 1 is $725,000 plus the cost of shutting down the Keno Canal for about 1 month. The estimated cost of Alternative 2 is $730,000. Alternative 2 would not require the Keno Canal to be shut down. The estimated cost of Alternative 3 is $670,000. Alternative 3 would not require the Ankeny Canal to be shut down.

Recommended Alternative

Fishway Alternatives 1 or 2 offer the best fish attraction conditions for river outlet operation and spillway operation at a similar construction cost. Re-entrainment concerns for fish existing fishway Alternatives 1 or 2 would likely require future changes in management of release gates to minimize use of gates adjacent to the fishway exit. For all fishway alternatives, dual vertical slot fishway baffles are recommended. This baffle design will pass about 25 percent more flow through the fishway and reduce the pool area consumed by large eddies. Fishway Alternative 3 is considered less desirable than Alternatives 1 or 2 due to poor fish attraction that would occur when large flows are released through the outlet gates and or spillway gates. Access for fishway maintenance is a concern for all three fishway alternatives. Sight constraints currently limit maintenance access downstream of the dam. Fishway maintenance access was beyond the scope of this study, but should be addressed in selection of a preferred alternative.

Table 3 - Concept Level Construction Cost Estimate for Fishway Alternative No. 1

CODE:D-3621

ESTIMATE WORKSHEET

SHEET 1 OF 1

FEATURE: 23-Apr-2001

PROJECT: Link River - Fishway

Link River Fishway Concept
East Bank Fishway, Alternative 1

DIVISION:

UNIT:

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PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
		Civil Works					
		Channel					
		Concrete		290	yds	$450.00	$130,500
		Reinforcement		35,000	lbs	$0.65	$22,750
		Cement		70	ton	$110.00	$7,700
		Earthwork (25% of the above)					$40,238
		Cofferdaming (gabion and earth)					
		compacted fill		360	yds	$5.00	$1,800
		rock gabions		360	yds	$25.00	$9,000
		unwatering (furnish and operate 250 gpm pump)		1	ea	$2,000.00	$2,000
		Mechanical					
		Removable Baffles					
		Steel		38,200	lbs	$3.00	$114,600
		Attraction flow structure					
		Steel diffuser panel (72 sf)		2,000	lbs	$2.00	$4,000
		Steel pipe (24 inch, 100 ft)		3,200	lbs	$2.50	$8,000
		24 inch gate valve		1,500	lbs	$4.50	$6,750
		Manually operated, fabricated steel slide gate 6' wide by 7' high, with pedestal		2,500	lbs	$8.50	$21,250
		Site access					$55,288
		Earth fill across canal and temporary roads (install and remove)		2,500	yds	$7.50	$18,750
		Mobilization (5 percent of above)					$21,194
		Subtotal					$463,819
		Unlisted items (25 percent)					$115,955
		Subtotal					$579,774
		Contingencies (25 percent)					$144,944
		Total					$724,718

QUANTITIES		PRICES	
BY		BY	CHECKED
DATE PREPARED	APPROVED	DATE	PRICE LEVEL

Table 4 - Concept Level Construction Cost Estimate for Fishway Alternative No. 2

ESTIMATE WORKSHEET

SHEET 1 OF 1

FEATURE: 23-Apr-2001 PROJECT: Link River - Fishway

Link River Fishway Concept
Mid-Channel Fishway, Alternative 2

DIVISION:

UNIT:

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PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
		Civil Works					
		Channel					
		Concrete		270	yds	$450.00	$121,500
		Reinforcement		32,000	lbs	$0.65	$20,800
		Cement		65	ton	$110.00	$7,150
		Earthwork (25% of the above)					$37,363
		Cofferdaming (gabion and earth)					
		compacted fill		720	yds	$5.00	$3,600
		rock gabions		720	yds	$25.00	$18,000
		unwatering (furnish and operate 250 gpm pump)		1	ea	$2,000.00	$2,000
		Mechanical					
		Removable Baffles					
		Steel and grid		38,200	lbs	$3.00	$114,600
		Attraction flow structure					
		Steel diffuser panel (72 sf)		2,000	lbs	$2.00	$4,000
		Steel pipe (24 inch, 50 ft)		1,600	lbs	$2.50	$4,000
		24 inch gate valve		1,500	lbs	$4.50	$6,750
		Site access					$50,964
		Prefabricated bridge		680	sf	$65.00	$44,200
		abutments and temporary roads (25% of bridge)					$11,050
		Mobilization (5 percent of above)					$19,536
		Subtotal					$465,513
		Unlisted items (25 percent)					$116,378
		Subtotal					$581,892
		Contingencies (25 percent)					$145,473
		Total					$727,364

QUANTITIES

BY

DATE PREPARED

APPROVED

PRICES

BY

CHECKED

DATE

PRICE LEVEL

Table 5 - Concept Level Construction Cost Estimate for Fishway Alternative No. 3

ESTIMATE WORKSHEET

SHEET 1 OF 1

FEATURE: 23-Apr-2001 PROJECT: Link River - Fishway

Link River Fishway Concept
West Bank Fishway, Alternative 3

DIVISION:

UNIT:

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PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
		Civil Works					
		Demolition of existing fishway		150	yds	$150.00	$22,500
		Channel					
		Concrete		270	yds	$450.00	$121,500
		Reinforcement		32,000	lbs	$0.65	$20,800
		Cement		65	ton	$110.00	$7,150
		Earthwork (25% of the above)					$37,363
		Cofferdaming (gabion and earth)					
		compacted fill		720	yds	$5.00	$3,600
		rock gabions		720	yds	$25.00	$18,000
		unwatering (furnish and operate 250 gpm pump)		1	ea	$2,000.00	$2,000
		Mechanical					
		Removable Baffles					
		Steel		38,200	lbs	$3.00	$114,600
		Attraction flow structure					
		Steel diffuser panel (72 sf)		2,000	lbs	$2.00	$4,000
		Steel pipe (24 inch, 100 ft)		3,200	lbs	$2.50	$8,000
		24 inch gate valve		1,500	lbs	$4.50	$6,750
		Site access					
		Prefabricated bridge		816	sf	$65.00	$53,040
		abutments and temporary roads (25% of bridge)					$13,260
		Mobilization (5 percent of above)					$17,188
		Subtotal					$427,251
		Unlisted items (25 percent)					$106,813
		Subtotal					$534,063
		Contingencies (25 percent)					$133,516
		Total					$667,579

QUANTITIES		PRICES	
BY		BY	CHECKED
DATE PREPARED	APPROVED	DATE	PRICE LEVEL

References

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Appendix - Reference Drawings

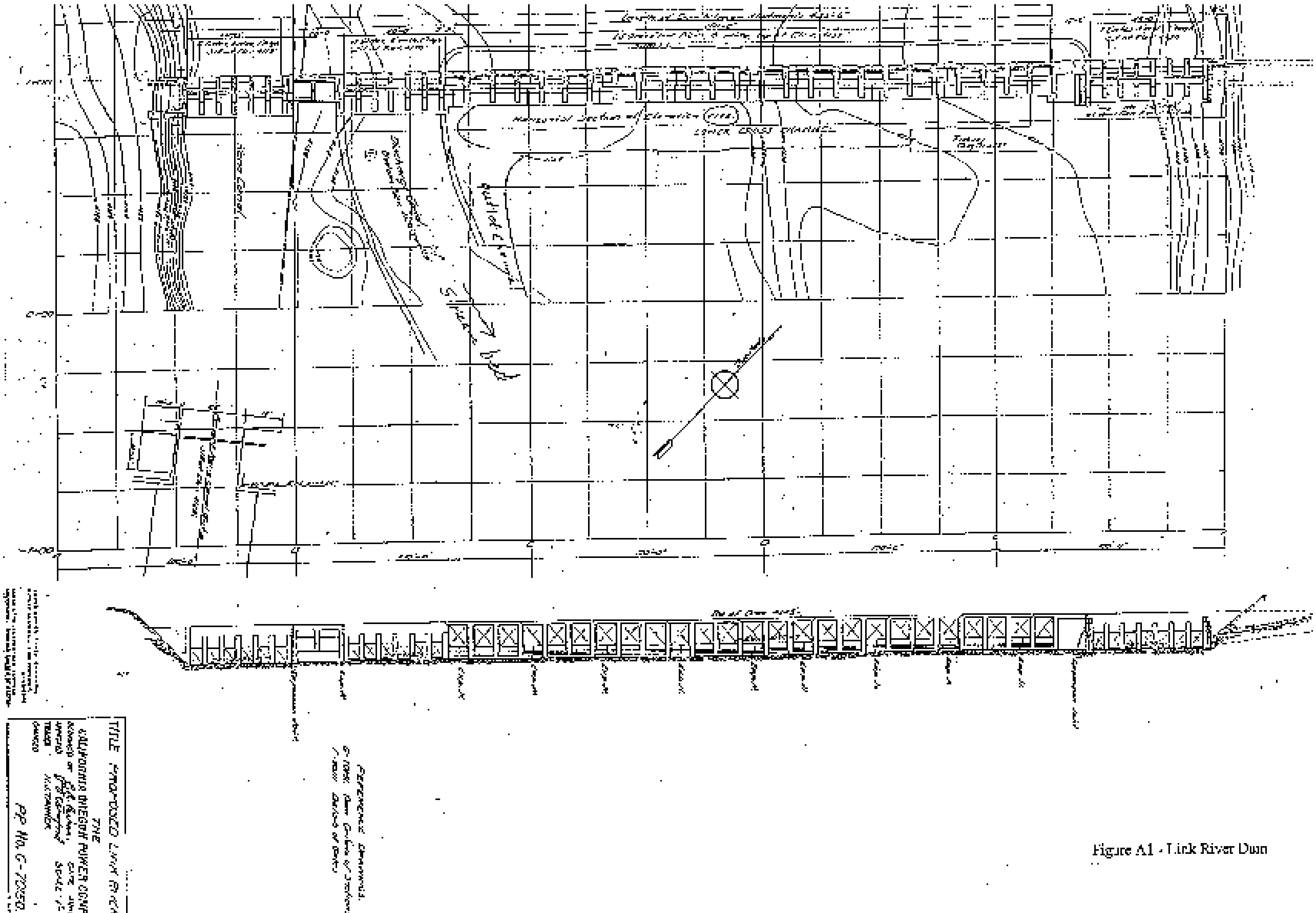

Figure A1 - Link River Dam

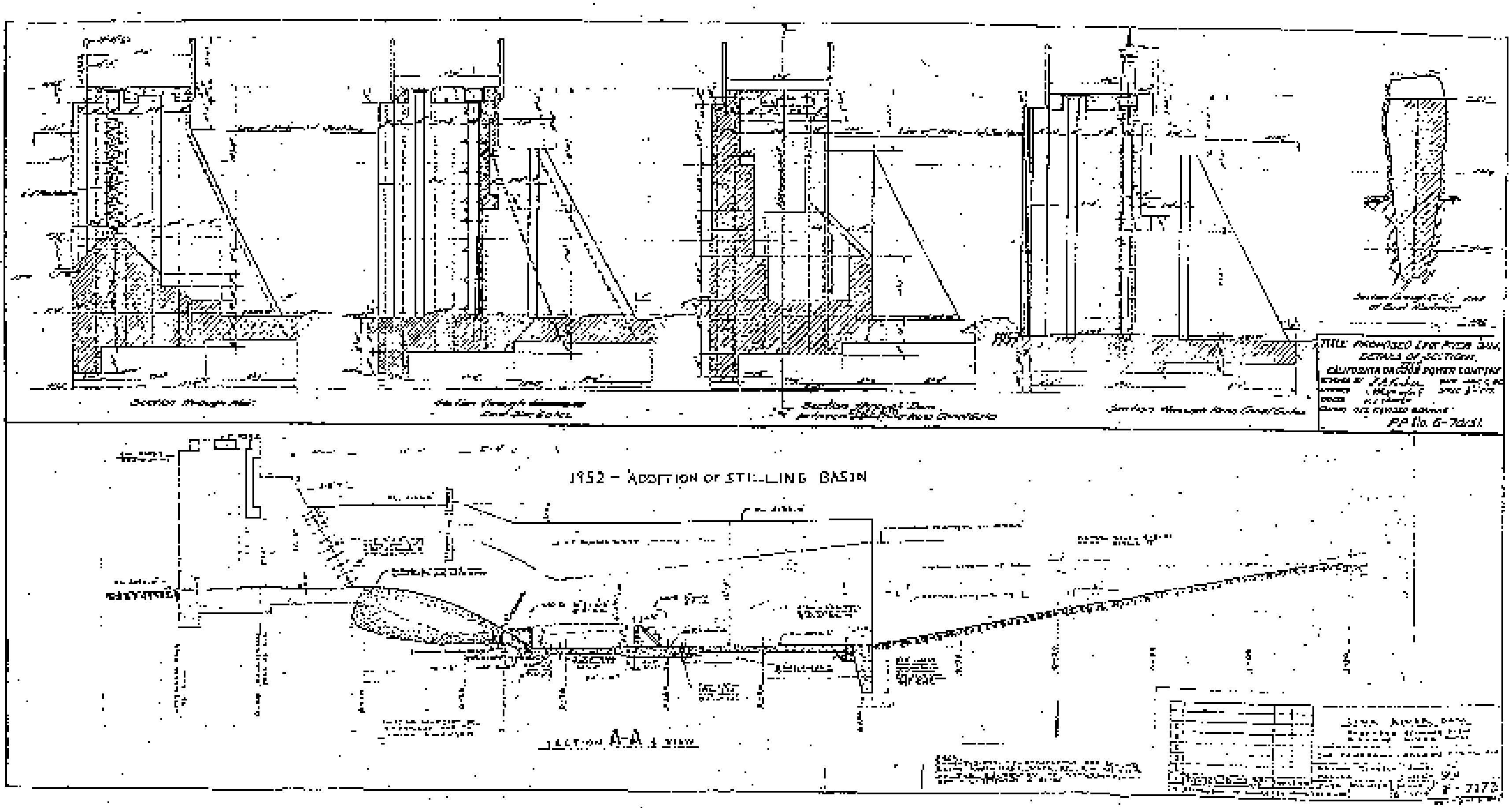

Figure A2 - Link River Dam river outlet stilling basin.

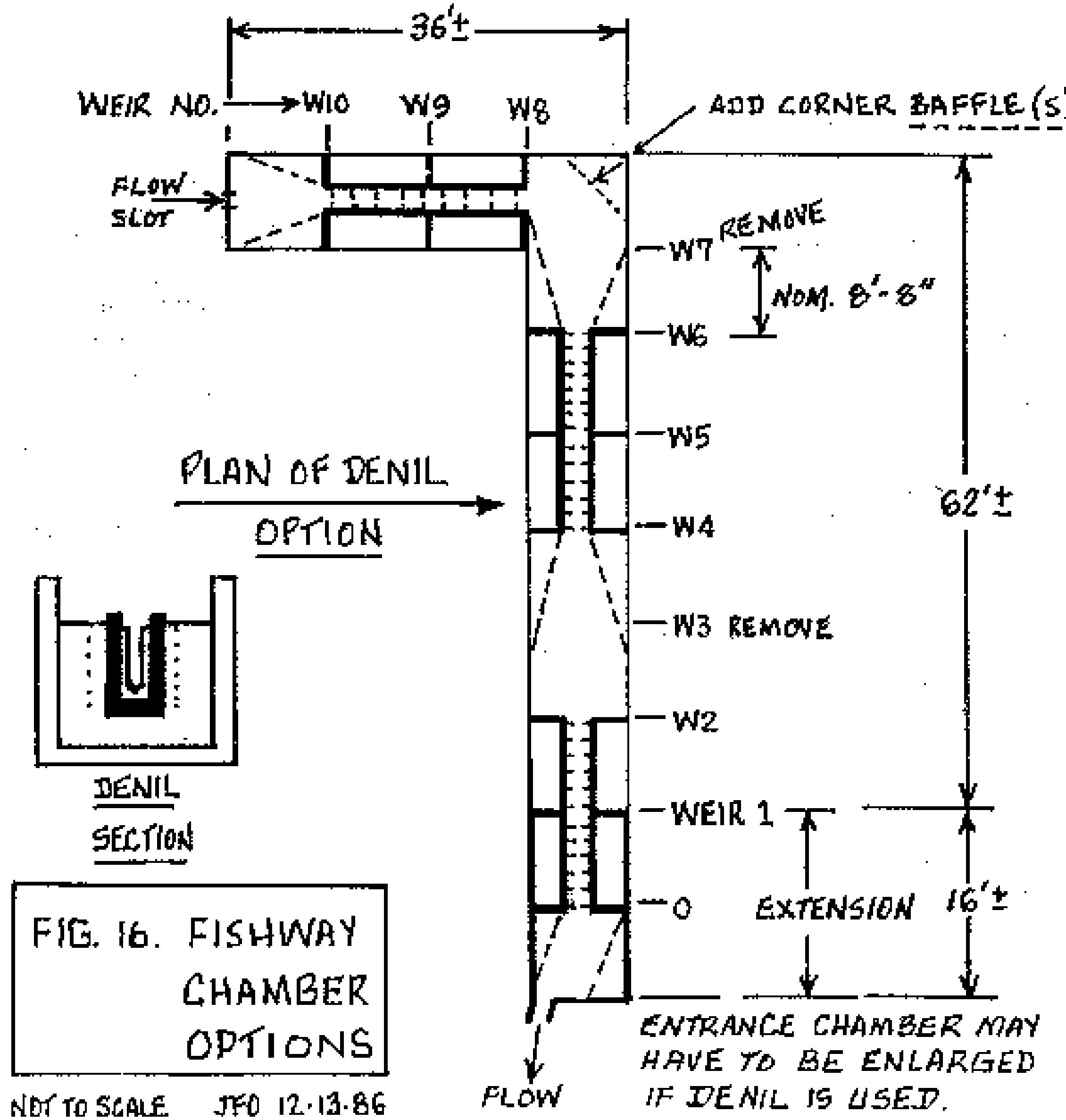

Figure A3 - Link River Dam fishway proposed by Orsborn, 1986.

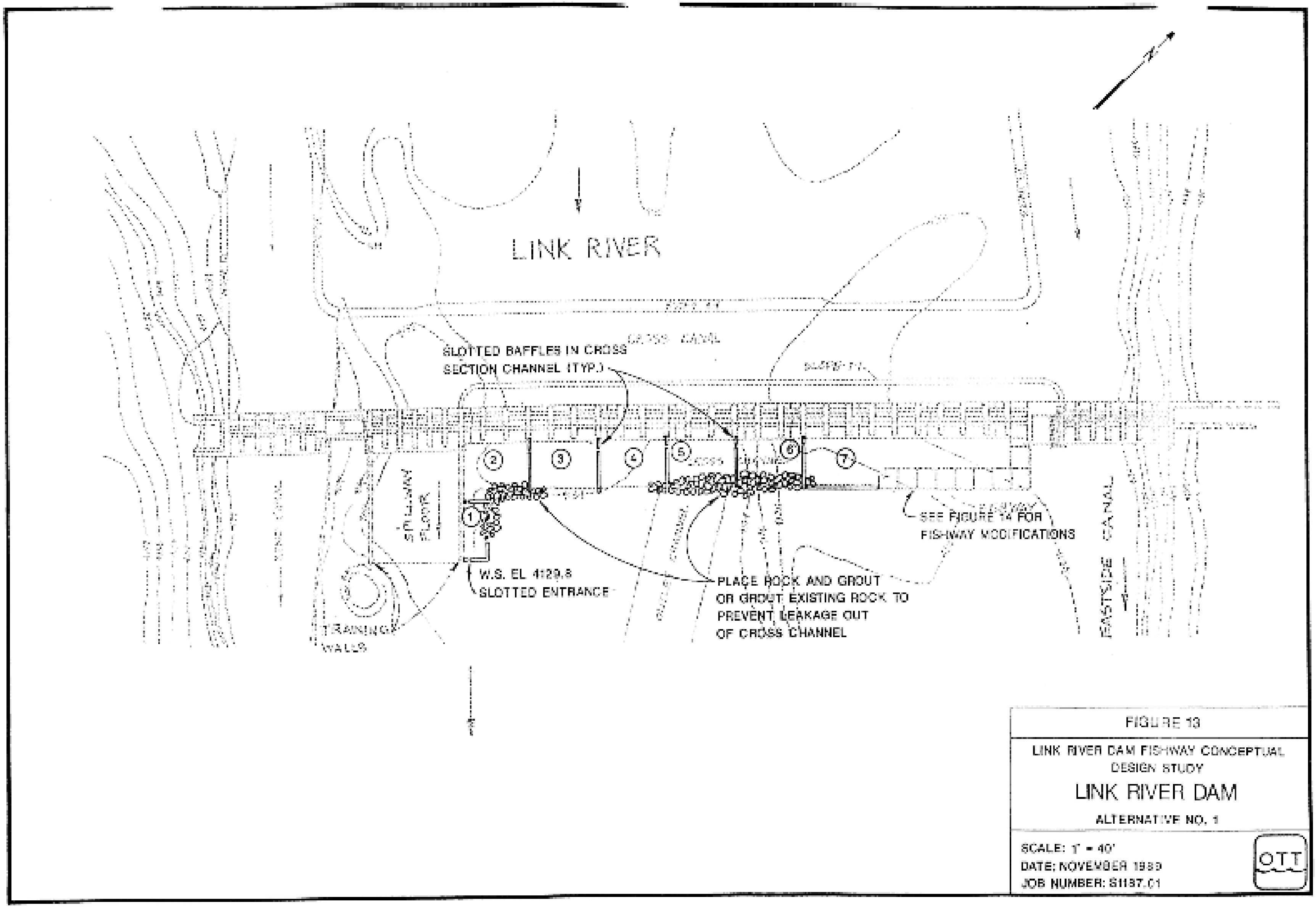

Figure A4 - Alternative 1 from the 1990 concept study by Ott Engineering.

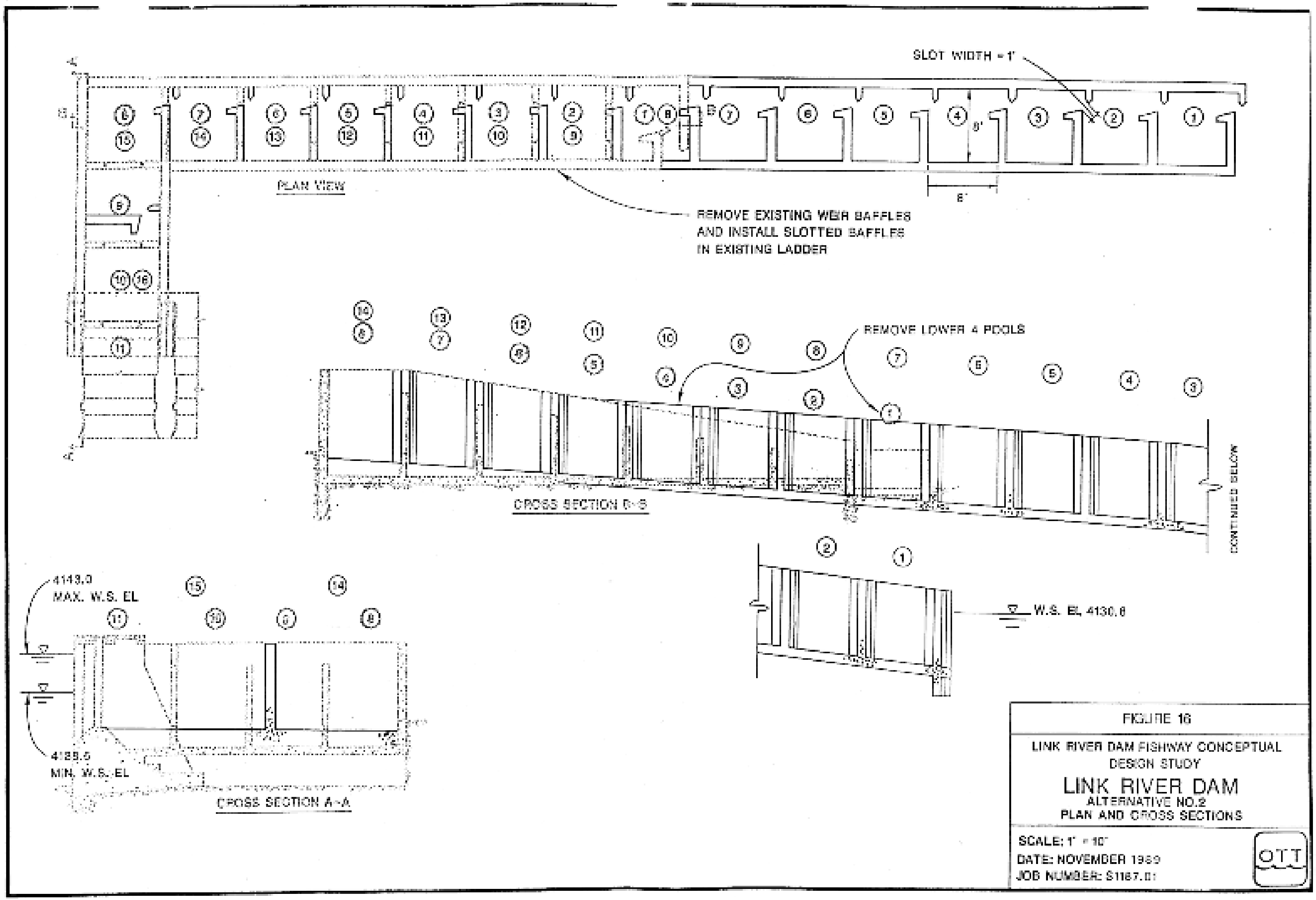

Figure A5 - Alternative 2 Link River Dam fishway concept proposed by Ott Engineering, 1990.