DESIGN OF CHANNEL FLOW DIVERSION FACILITIES FOR RIPARIAN HABITAT IRRIGATION

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ABSTRACT

Increased awareness and concern regarding environmental degradation has resulted in protection of the riparian and river ecosystems. A variety of construction projects are now required to provide wetland and riparian habitat mitigation as a part of regulatory permit requirements or stormwater quality enhancement. One of the primary elements in developing a successful riparian enhancement ecosystem relies on ensuring an adequate water supply source, in addition to, adequate soils type and suitable vegetation. Developing a satisfactory water supply becomes a critical design issue particularly in semiarid areas, such as Southern California, where most of the natural ephemeral streams will not sustain a significant year round flow. Water supply must be able to (1) meet the anticipated demand of the vegetation, (2) provide for variable losses from infiltration and changes in seasonal evaporation, (3)develop from a natural source, and (4) require limited maintenance. "Offline" habitat replacement areas provide the opportunity to develop an effective water supply source from the adjacent floodplain or channel for irrigation of the riparian vegetation through the diversion of limited flows. Numerous types of hydraulic structures have been incorporated into flood control channel systems as **flow diversion** facilities for habitat irrigation that involve unique design features, particularly those in active alluvial streams and floodplains.

Fundamental design guidelines which have been utilized on successful diversion systems and have addressed these unique design/operation issues are explored in detail. Various diversion structure configurations are presented, which includes the layout requirements and appurtenant facilities which enhance the operation / long term maintenance. Typical hydraulic design requirements for these facilities is presented which includes (1) sediment control, (2) hydraulic operation, (3) maintenance, (4) regulating flows, and (5) evaluation of high and low stage requirements. Design of these facilities relies on careful selection of the appropriate site location and detailed understanding of the stream mechanics, both sediment and hydraulics. The diversion facilities consist of three critical components which include: (1) in-channel interception device, (2) conveyance system, and (3) outlet facility into the habitat area. Each of these elements have independent design issues which must be addressed in order to guarantee the successful operation. A case study is included which reviews the design of a unique multi-chambered diversion facility in Southern California which attempts to address many of the common deficiencies and operational problems through inherent special design features.

INITIAL PLANNING GUIDELINES AND DESIGN ISSUES

The initial planning requirements for the incorporation of an "in-channel" diversion facility for habitat irrigation are very project specific to ensure that the facility performance meets both the engineering and environmental objectives. These types of facilities are becoming more routinely incorporated into flood control projects with offline habitat replacement areas as part of environmental regulatory permitting requirements and also stormwater quality enhancement features. The importance of an adequate and sustainable irrigation supply especially during dry periods is extremely critical in semi-arid environments where a majority of these type facilities have been developed. Diversion facilities rely on the ability to change the direction of flow in the channel for a variety of flow conditions and redirect the flow to the irrigation conveyance facility or directly to the off-channel habitat area. Utilizing this type of feature requires integration into the overall environmental management program and river engineering design. The highly variable hydrologic and hydraulic conditions modify the individual facility requirements and limit the functional alternatives available. Many useful guidelines can be adopted from the common large-scale diversion works typically used for river and reservoir control.

Detailed Watershed Investigation - Establishing an accurate baseline foundation of the watershed characteristics is a key element since this forms the basis for all technical analysis related to the facility. Detailed hydrology investigation should include not only the maximum design storm, but also the dry weather conditions to assist water budget analysis to satisfy the water demand of the habitat vegetation.

Alluvial Stream Mechanics and Sediment Delivery - Detailed understanding of the alluvial stream hydraulics is necessary to evaluate the stability of the streambed through the potential effects of degradation and scour. Streambed adjustments both long term and short term must be analyzed to effectively determine the requirements of the structure. The magnitude of the watershed sediment yield and debris production must be quantified to evaluate the effects from the structure and if sediment control measures must be incorporated into the facility.

Estimated Water Budget Requirements - The facility sizing for the diversion headworks and conveyance system relies on the water demand which must be provided to the habitat vegetation. A water budget should be performed to estimate the demand for the vegetation in "dry-weather" conditions. Particular attention should be applied to the initial establishment period to ensure a high survival rate of the vegetation.

Optimum Facility Location - Much of the site selection for a diversion facility depends on the location and elevation of the offline habitat area. The site must be selected where the stream or alluvial channel is comparatively narrow and stable. It is desirable to select a location which allows flexibility to adjust the river cross section or hydraulic control, including elevation differential. The potential influences to other structures within the channel must be examined if the structure relies on developing a tailwater, including modification of sediment transport.

Sediment Control and Sluicing - Sediment deposition control is one of the critical design issues to address to ensure the functional design of the facility, since sediment can increase the long term maintenance requirements and reduce short term effectiveness. Sediment control features can include methods of bypassing or sluicing sediment bedload through (1) bedload deflecting sills, (2) sediment bypass conduit or channel, and (3) in-line sediment pre-settling basin. Reduction of sediment in the diverted flow to the irrigation system headworks since this can potentially result in clogging the irrigation conveyance system.

Irrigation Conveyance/Delivery Facilities - The diversion headworks facility located in the channel must be able to deliver the water to the habitat area through some type of conveyance system. The diversion works can function as a detailed flow distribution facility, such as drip irrigation for individual plantings or a distribution pipe network. Generally, these facilities are physically limited in the available gradient for the vertical profile and it is important that a non-settling velocity be maintained. Removal of a majority of the suspended sediment or at a minimum the bedload should be accomplished at the diversion headworks.

Channel Hydraulics and Impacts - Development of a baseline hydraulic evaluation of the channel is essential to establish the hydraulic characteristics. The baseline hydraulic model can be utilized to analyze alternative facilities and quantify the hydraulic impacts.

Evaluation of Extreme Range of Operational Conditions - Analysis of the hydraulics of the structure should include a range of operating conditions to ensure that the necessary features have been included or different impacts may surface. Typically a range of discharges must be evaluated which include the "dry-weather" or low-flow and the larger design storm for flood protection.

Flow control / regulation - The ability to isolate the diversion headworks system from the channel or adjust the amount of flow conveyed to habitat area is a useful feature. However, it is also desirable to develop a system that can operate automatically with minimal manual control. Incorporating valves or gates into the facility will be provide the flexibility

Maintenance Features and Requirements - The design must focus on minimizing the potential for long term maintenance or if maintenance is required then there should be adequate provisions to facilitate access. Maintenance features include provisions for sediment removal, debris collection, isolation of the system for maintenance, access, central sediment removal location, and sediment sluicing.

COMMON TYPES OF CHANNEL DIVERSION FACILITIES

Various channel diversion facilities have been implemented in the Southern California area with varying degrees of success. Changing the natural direction of flow within the channel for an intake structure is generally accomplished through either (1) ponding the flow in back of a barrier, (2) withdrawal within the channel bottom through an interception device ,or (3) not controlling the main channel flow and bypassing only a portion based upon the flow distribution at the side intake structure. Most common diversion facilities for flood control habitat irrigation have been based upon hydraulic diversion structures commonly applied in irrigation canals or used for reservoir operation. Some common configurations of these facilities include the following:

Inflatable Rubber Dams - A more innovative method for in-channel flow containment is through the use of heavy duty inflatable rubber bladders which have the ability to deflate quickly, removing the obstruction in the channel depending on flood conditions. Inflatable dams have low maintenance requirements and high longevity, common warranties extend for thirty years. The bladder for the dams are typically made of one inch thick rubber imbedded with a fabric mesh and ceramic chips. The height of the dam inflation provides the ability to regulate flow within the channel or create a tailwater to divert flow to the irrigation intake facility. Two manufacturers in the world manufacture this product and include Sumigate and Bridgestone. This type of facility would require telemetry or manual operation.

Interception Channel or Withdrawal Trough - An invert channel withdrawl facility generally consists of a small incised trough or pit constructed across the entire width of the channel to collect and direct low-flows to the intake facility at the sides of the channel. Grates are commonly placed over the interception channel to prevent debris from clogging the smaller intake conveyance system and for public safety. These types of facilities are more commonly applied in completed lined channel systems, and are one of the few installations which can be utilized for supercritical channels.

Channel Profile Adjustment - The vertical alignment of the channel invert can be modified to incorporate designed channel depressions or locations of adverse grade. These adjustments in the channel profile will generally not be significant enough to modify the hydraulic performance during the larger design storm event, but should be adequate to influence nuisance or low-flows.

Low-Height Weirs / Embankment (Stilling Basins) - A common concept for a channel diversion facility is to block the main channel flow with a small height raised weir or reinforced embankment within the channel bottom. The low-height obstruction will result in ponding or reduction of velocity to enhance the opportunity to change the main flow direction in the channel to the intake headworks. Typical configurations of these in-channel weirs have included: (1) low-height vertical concrete wall, (2) trapezoidal soil cement sections, (3) sheet pile wall (steel, concrete, and vinyl), and (4) earthen trapezoidal section with protective revetment. Additional features which can be incorporated into the primary weir are variable height and width notches to control low-flows or allow downstream flow by-pass. Low-level orifices through the obstruction can be incorporated to allow sluicing of sediment bedload deposited upstream of the weir. An important consideration is that these permanent obstructions to channel flow will influence the hydraulics of the channel, especially during the larger design storm event.

Combined Use with Grade Control Structures - Grade control facilities provide one of the few opportunities in an alluvial channel system to create an in-channel control for flow diversion other than dam. The grade control structure has many other unique characteristics which facilitate the development of a flow diversion structure include: (1) elevation differential to facilitate sediment and flow bypass, (2) established hydraulic control, (3) invert control across the entire channel basewidth, and (4) potential to provide sediment pre-settling at the grade control headworks. An interception system located within the grade control structure has proven to be an effective design while the use on a obstruction to create a ponded condition will result in higher maintenance. The interception system can include a transverse channel on the downstream side of the grade control crest.

Side Weirs - Weirs located along the sides of a channel can be constructed at crest elevations lower than the surrounding top-of-channel to allow overflow into adjacent offline habitat areas. This type of facility will protect the habitat vegetation from the hydraulic forces of the channel flows and allow flushing during larger storm events. However, this type of facility is not effective to allow the control of nuisance flows or low-flows unless the weir crest elevation is located near the channel bottom.

Urban Storm Drain Diversion Facilities - Diversion facilities are commonly constructed within underground storm drain facilities in urban areas to divert nuisance flows and first flush discharges to facilities which include wetlands. The diversion can be accomplished with underground in-line structures or "smart-boxes" which incorporate weirs or orifices to hydraulically control flow distribution based upon depth of flow. Another effective method is the construction of an in-line withdrawal pit that is located below the flow line of the storm drain at an appropriate location such as a manhole.

COMMON INHERENT OPERATIONAL PROBLEMS

Operation of any hydraulic structure within an active alluvial floodplain or flood control channel can experience numerous problem, particularly due to the fact that the channel system is extremely dynamic and susceptible to variable conditions. Some common operational problems include the following:

1. Lack of hydraulic control within the main channel
2. Inadequate quantity of flow diversion with significant bypass to the main channel
3. Debris clogging the headworks
4. Downstream local scour below the headworks facility
5. Sediment deposition upstream or within the headworks facility
6. Hydraulic disturbances and diminished level of flood protection
7. Sedimentation in diversion conveyance pipeline
8. Damage to structure from large bedload material and debris

DESIGN APPLICATION: SAN DIEGO CREEK DIVERSION FACILITY (IRVINE, CA)

A proposed habitat replacement area in Irvine, California, will be constructed as part of the Barranca Parkway roadway extension and San Diego Creek flood control improvements, in conjunction with the adjacent residential development by the Irvine Community Development Company. The replacement area will provide the required habitat mitigation for the roadway project and channel improvements which will intersect portions of the existing natural San Diego Creek floodplain, removing natural riparian habitat. The San Diego Creek watershed at this location has approximately 33.9 square miles tributary, with an estimated ultimate100-year design flow of 17,400 cfs. The habitat replacement area will consist of approximately 8.4 acres of riparian landscaped area and located on the northwest side of the Barranca Parkway extension, directly adjacent to the roadway. The majority of the habitat area consists of portions of the original San Diego Creek floodplain to be preserved. The vegetation primarily includes a riparian mixture of mulefat and willows, with an upland transitional element for the side slopes consisting of oaks. The long term operation of the habitat replacement area requires a natural gravity water supply with a maximum demand of approximately 5 cfs, although a temporary irrigation system will be provided to guarantee the initial establishment. The proposed system will rely on diverting water flowing with the alluvial streambed of the adjacent San Diego Creek Channel to the habitat area. The flow will be collected and diverted from the channel through an **"in-channel" diversion structure** which will be maintained by the City of Irvine and is not considered as part of the regional flood control system for San Diego Creek. The diverted flow from the channel will be conveyed to the habitat replacement area through an 18-inch diameter underground storm drain pipe system approximately 2,220 lineal feet. The flows delivered to the habitat area which exceed the water supply requirements can be returned to the channel through a 72" diameter return storm drain pipe at the downstream end of the habitat area which crosses Barranca Parkway. The channel diversion structure is only one source of gravity storm flows to the habitat area and the other source is the existing 84" diameter storm drain which drains an existing residential development area that should provide constant supply of urban nuisance flows.

The diversion structure is being constructed as part the flood control channelization project for this portion of San Diego Creek which allowed flexibility in the design program to ensure the diversion structure facility could be successfully integrated into the hydraulic design of the channel system. The flood control improvements associated with the San Diego Creek project involve channelization of approximately 5,350 lineal feet of natural floodplain between existing upstream and downstream channelized portions of San Diego Creek. The channel improvements will consist of both soil cement slope revetment with an earthen channel bottom, and composite section consisting of soil cement or pinned prefabricated concrete block (PPCB) slope revetment with a cellular concrete block mattress invert lining. The existing channel system upstream and downstream of this project consists of an engineered section with an alluvial stream bottom.

UNIQUE DESIGN ISSUES AND OPERATIONAL REQUIREMENTS

The critical design issues associated with the San Diego Creek "in-channel" diversion structure include: (1) sediment deposition in the diversion storm drain to the habitat area, (2) sediment deposition in the structure, (3) debris clogging, (4) ability to intercept the channel low-flows, (5) ability to regulate or isolate the diversion storm drain for maintenance, (6) self-cleaning operation, and (7) ability to function under high flows and low flows. A three chamber system was selected which allows (1) low flows to be collected, (2) separation of a majority of the sediment bedload to provide a clearwater flowrate to the diversion storm drain, (3) return the sediment to the channel through a bypass storm drain. The proposed system is similar in concept to the irrigation headworks system on an adjacent watershed which was successfully operated for several years and the adjacent offline habitat area. This existing facility is located within a very active alluvial stream system.

The system has been designed primarily to intercept the "dry-weather" flows which are critical to ensure the survival of the habitat area. During the high storm periods there is the potential for floating debris which will be removed from entering the system through a debris rack. Also, high flows will be delivering significantly more sediment bedload across the interception structure which encompasses approximately 12% of the channel width. In order to bypass the higher amount of bedload, the "return storm drain" has been sized for the maximum allowable head within the structure and metal cover plates prevent in-channel flows from directly discharging into the diversion chamber. The objective is to minimize the potential for sediment deposition in the 18" diameter diversion storm drain line and provide a hydraulically self cleaning system through manual adjustments of the slide gates

DESCRIPTION OF FACILITY COMPONENTS

The diversion structure is located at the headworks of the proposed channel improvements in order to utilize the maximum elevation differential which can be incorporated into the depth of the structure and the gradient of the connecting storm drain pipes. The diversion facility relies upon a concrete breast wall or cutoff wall across the entire channel bottom width to assist in diverting low-flows within the earthen channel streambed to the location of the inlet structure. The concrete cutoff wall also serves as the termination point for the armorflex® channel bottom lining which continues downstream and provides erosion protection for the structural channel slope revetment. The three primary elements of the structure include the **(1) interception chamber, (2) bypass chamber, and (3) diversion chamber**. The system is based upon other successful "in-channel" diversion systems in order to minimize maintenance and ensure the opportunity to deliver a natural gravity water source for the habitat replacement area that will be primarily self-operating.

1. Interception Chamber: The interception chamber is the initial structure which is exposed to channel flows and intercepts the flow through either the twenty-foot long weir or high flow occurring over the debris rack. Flow has three different potential paths out of the chamber which includes the (1) slidegate to bypass chamber which bypasses the sediment flow, (2) high weir crest to the bypass chamber, and (3) low-weir to the diversion chamber. The general operation will require the slidegate be slightly open to allow continuous clean out of sediment deposition in the chamber and the gate will allow water to pond in the chamber until clear water discharges into the diversion chamber.

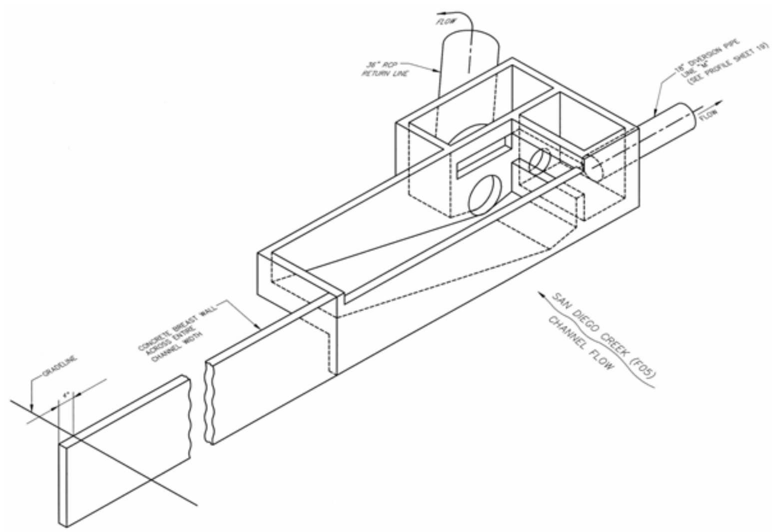
2. Bypass Chamber: All unused flow and sediment laden flow is released to the bypass chamber to be returned into the San Diego Creek channel through the bypass storm drain.

3. Diversion Chamber: The diversion chamber allows flow to be collected into the diversion storm drain. Two different gates are provided to allow isolation of the storm drain.

4. Diversion Storm Drain: An 18-inch diameter storm drain from the diversion chamber to the habitat area which delivers a maximum of 5 cfs the irrigation water.

5. Bypass Storm Drain: A 36-inch diameter storm drain from the bypass chamber to the San Diego Creek channel immediately downstream of the structure. The storm drain allows bypassing the bedload to the channel and minimizing sedimentation in the storm drain. The maximum hydraulic capacity of this system is estimated to be 16 cfs.

The low-flow operation of the diversion structure relies on standard hydraulics for weirs and orifices. The weir elevations of the interception chamber and the weir to the diversion chamber were developed to ensure the same hydraulic capacity at the maximum depth to the top of the structure. The structure is gated to allow isolation and regulation of the amount of flow.



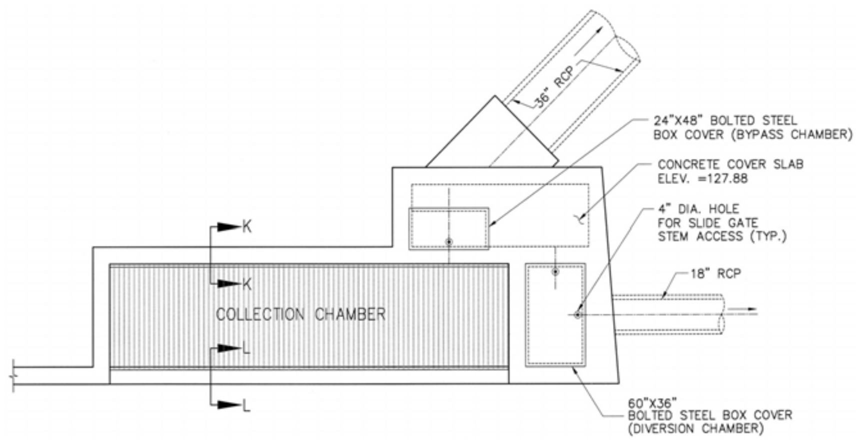
ANTICIPATED OPERATION

1. Low- Flow / Dry-Weather Periods: Low-flows within the existing San Diego Creek channel upstream of the diversion structure headworks develop a meandering thalweg within the earthen channel bottom. The flow approaching the concrete breastwall at the structure headworks (located across the entire channel) will naturally gravitate to the low-point along this wall, which is the enterance weir to the collection chamber. If sediment deposition or naturally occurring planforms in the alluvial streambed prevents the thalweg from naturally meandering to this location, then minor corrective maintenance action to guide the flow would be required. The corrective action would include grading the thalweg to the entrance weir or the construction of a small earthen diversion berm. The mechanical slide gate between collection chamber and diversion chamber would be open slightly to sluice the sediment which will accumulate at the low-point in the collection chamber adjacent to the slide gate

2. High Flows / Winter Season: During major storm periods the mechanical gates should be closed to the diversion pipeline because of the large sediment bedload transported by the channel. This will minimize deposition within the diversion pipeline to the habitat area. The other gates should remain completely open during the winter season to minimize the deposition in the chambers. However, it is anticipated at the end of the storm season that sediment removal will be required in the chambers, even with the steel hatch covers over the other chambers.

ESTIMATED HYDRAULIC CAPACITIES OF INDIVIDUAL STRUCTURE ELEMENTS

Simplified hydraulic analysis can be performed to evaluate the initial hydraulic requirements and facility sizing. These simplified calculations should be adequate to accurately determine the facility requirements since the primary condition of interest is the ability to deliver low-flows. More extensive hydraulic analysis can be performed after the initial facility sizes and geometry has been developed. This simplified evaluation for the San Diego Creek facility is indicated below:



1. Collection Structure - Channel Entrance Weir:

Maximum head on weir is one foot on a 20-foot long weir. Assuming a weir coefficient of 3.0 for this head.

$Q = CLH^{3/2} = 3\ (20)\ (1.0)^{1.5} = 60$ cfs

Note: depths exceeding one foot at the entrance weir for the structure will flow over the breast wall and continue down the main channel, bypassing the structure.

2. Diversion Structure Hydraulics:

Flow from the diversion structure chamber can only enter from the collection chamber through the elevated weir. The weir crest is located 1.16 feet below a similar weir in the collection chamber connecting the bypass chamber. Water will initially flow into the diversion chamber until the depth of ponding exceeds 1.16 feet above the diversion chamber weir crest or approximately 18.7 cfs. As the flow in the collection chamber continues to rise then flow will spill into both the diversion and bypass chamber. The maximum flow that can discharge over the two weirs before the water depth will seal the opening is 47.6 cfs to the diversion chamber and 15 cfs to the bypass chamber. The maximum flow that these openings can discharge when operating as an orifice with the depth of flow to the top of the chamber is 66.9 cfs to the diversion chamber and 24 cfs to the bypass chamber. A portion of the flow will be diverted to the bypass chamber through the gated 18" opening which connects the collection chamber. The flow which is sluiced to the bypass chamber will contain the majority of the sediment and the amount of flow will vary depending upon the regulation of the opening height. The control heights and settings for the gate will be determined through field operation.

$Q_{\text{diversion weir}}$ (depth before bypass spill) = $3\ (5)\ (1.16)^{1.5} = 18.7$ cfs
$Q_{\text{diversion weir}}$ (max ponding depth) = $3\ (5)\ (2.16)^{1.5} = 47.6$ cfs

$Q_{\text{diversion weir}}$ (orifice flow max depth) = $CA(2gh)^{0.5} = 0.63\ (10.8)(2\ (32.2)\ 1.5)^{0.5}$

where the head for the orifice flow is measured to the centroid of the flow area

3. <u>Bypass Chamber Hydraulics</u>:

-Maximum depth when operating as weir before sealing
$Q_{\text{weir}} = 3(5)(1)^{1.5} = 15$ cfs
$Q_{\text{orifice}} = 0.63\ (5)(2\ (32.2)\ 0.92)^{0.5} = 24$ cfs

·Maximum flow between bypass chamber and collection chamber through the 18" diameter circular slide gate based upon inlet control.

HW/D = 6.38 / 1.5 = 4.25
From inlet control nomograph $Q_{\text{inlet}} = 16.0$ cfs

4. <u>Bypass Storm Drain</u>:

· Check the operation for the flow full capacity of the 26" diameter storm drain assuming both inlet control and normal depth based upon the friction slope equal to the pipe slope.

HW/D =6.88 / 3 = 2.29 From inlet control nomograph $Q_{\text{inlet}} = 23.0$ cfs

$Q_{\text{full flow capacity}} = (0.463/0.013)\ (3)^{8/3}\ (0.0058)^{0.5} = 50.8$ cfs

This indicates that the maximum capacity of the bypass storm drain would be 23 cfs before the depth of ponding would overtop the breastwall of the structure and allow flow into the channel.

SUMMARY

In-Channel diversion facilities offer the opportunity in semi-arid areas to provide an effective method for an irrigation supply to off-channel habitat replacement areas. Careful design and planning is required for these facilities to ensure successful operation and long term survival of the habitat areas. The designer must verify that the facility is capable of operating in a variety of conditions and a range of parameters which reflect these conditions must be evaluated, including the initial startup to the long-term establishment of the habitat area.