FISCAL YEAR 1996 PROGRESS REPORT

STREAM RIPARIAN ECOLOGY SECTION
MIDCONTINENT ECOLOGY SCIENCE CENTER
NATIONAL BIOLOGICAL SERVICE

WORK UNIT/PROJECT: Improve Analytical Techniques for Restoration and Management of Habitat in Western Gravel-bed Rivers.

STUDY/TASK TITLE: Improve Analytical Techniques for Restoration and Management of Habitat in Western Gravel-bed Rivers. (Flushing Flow Project)

BACKGROUND

The U.S. Fish and Wildlife Service field offices often requested assistance form the National Ecology Research Center in the analysis of water resources projects where the link between sediment and the aquatic habitat is important. These requests have steadily increased over the past eight years. In addition, many have requested that flushing flow analysis techniques be added to existing instream flow methodologies. In the early days of IFIM, the focus was on salmon and trout; this has expanded to other fish species and aquatic animals other than fish. Prior to FY92, the NERC made progress in improving the instream flow techniques available for analyzing flushing flow needs and other aspects of sedimentation as a component of technical assistance activities to the various field offices. NERC work had progressed to the point that lack of information that could only be obtained from laboratory experiments was limiting progress. At the same time the U.S. Bureau of Reclamation (USBR) had become aware of the need to develop techniques for determining flushing flow needs and had discussions with the Colorado Endangered Species Recovery Team about the possibility of doing work in the laboratory but did not have the expertize to expand the results to numerical modeling. The fact both agencies had the expertize the other needed made a joint project a very desirable activity from the viewpoint of both NERC and of the Hydraulics Laboratory.

During the last half of fiscal year 1991, a proposal for joint work between the National Ecology Research Center and the Hydraulics Laboratory of the U.S. Bureau of Reclamation was written and submitted to research managers in both organizations. The proposal was a responses to the desire of the Secretary of Interior that the USFWS and USBR do joint work on projects of mutual interest where the combined efforts of the two agencies would have better results than if the agencies worked alone. The proposal was funded by both agencies for fiscal year 1992 and in fiscal year 1993.

The FY93 funding was much less than the funding requested in the original proposal. The NBS FY94 funding was reduced even further to the determent of the project. Funding during FY95 and FY96 was the same as FY94.

The objective of the joint study is to develop improved analytical techniques for the analysis of flushing flow needs. These improved techniques are needed in order to determine a flushing flow need as an element of an instream flow need that can be supported and defined during the process of negotiating the instream flow need.

The project has three major components: the construction and use of physical models, the development of numerical models, and the testing of the results from the first two components in the field. The work on physical models has two parts: the use of a flume to study physical processes for which information is needed to do numerical modeling and a three dimensional model of the stream reach that will be used for the field studies. The National Ecology Research Center has the lead in numerical modeling and the USBR Hydraulics Laboratory has the lead in physical modeling. Field work will be needed to collect data for a test reach of stream for both the physical and numerical modeling. The field work is a joint activity of both agencies.

At the beginning of fiscal year 1994 the National Ecology Research Center became an element of the National Biological Survey. The center was renamed the Midcontinent Ecological Sciences Center in mid-1994. Work for the years prior to fiscal year 1994 is presented as National Ecology Research Center (NERC), for 1994 and the years following it is the Midcontinent Ecological Sciences Center (MESC). The Hydraulics Division is now the Water Resources Research Laboratory.

FISCAL YEAR 1992 ACTIVITIES

The work planned for 1992 was 1) to develop a plan of study, 2) to select the site for the field study and three dimensional model study, 3) to design and construct the flume for the laboratory experiments, 4) to develop bed-material sampling procedures, 5) to begin field data collection at the field test site and 6) improve working relationships between the USBR and USFWS.

DEVELOP STUDY PLAN

The study plans developed during FY92 for the study were the responsibility of each agency (USBR Hydraulics Laboratory and NERC) and only for the work of that agency. A joint study plan is was not done in FY92 because of uncertainties in funding. Separate study plans were completed for the NERC portion of the study and for the USBR hydraulics division portion of the study. The joint proposal written in FY91 was the guiding document for each study plan.

SELECT SITE FOR FIELD TEST

The hydraulics laboratory sent a questionnaire to Regional Offices of the USBR requesting information on the nature of flushing flow problems in the region and asking if the region was interested in participating in the study. NERC had made a commitment prior to funding of the study that the field test site would be in USFWS Region 6.

Possible field test sites were identified in California, New Mexico, Wyoming, and Colorado. The test site selected is the Gunnison River in Colorado below Delta and above Whitewater. Secondary and backup sites were selected on the Stanislaus River in California, the Rio Chama in New Mexico, and the North Platte above Casper in Wyoming.

DESIGN AND CONSTRUCT FLUME

The design of the flume was done by Russ Dodge of the USBR Hydraulics Laboratory. The flume is actually a duct and is a creative departure form common practice. The USBR made a major commitment of resources in the design and construction of the flume. The flume was completed during FY93.

DEVELOP SUBSTRATE SAMPLING TECHNIQUES FOR THE FLUSHING FLOW STUDY

During the field work to locate a site for the three dimensional model and for a test of the flushing flow methodology it became obvious that one important factor not understand is the best technique for sampling the bed-material (substrate). A major effort was started to develop sampling procedures. Some of the work was done by staff of TGS Inc. under a task order from NERC and part by staff of Colorado State University (CSU) under a sub-contract with TGS Inc.

Samples from the Stanislaus, Rio Chama and North Platte Rivers will also be obtained as part of the work being done by TGS and CSU. The initial work on developing sampling techniques and the sampling of the secondary sites was completed by TGS and CSU during FY93. The final report has 1) a review of the literature that describes techniques, 2) a description of improved techniques, and 3) a presentation of the results of field studies.

The work on the North Platte is the test area for determining techniques for substrate sampling. The reason for starting on the North Platte is that the river is relatively small compared to the Gunnison and there are low flow periods on the river that allow sampling. Also the river contains sand and other fines that can be flushed out by an increase in flows. During a site visit in April 1992 considerable sand was observed at on location almost completely covering the gravel material below; by August 1992 most of this material had been removed.

The Stanislaus is include in the sampling development work because it represents a river without a large amount of cohesive fines but with considerable sand.

COLLECTION OF DATA FOR PHYSICAL AND NUMERICAL MODELING OF THE GUNNISON RIVER FOR THE JOINT USFWS/USBR FLUSHING FLOW STUDY

The 1992 objective was to obtain the data needed for construction of a three dimensional physical model and for development of both one-dimensional and two-dimensional numerical techniques. The site for field testing is on the Gunnison River in Colorado between Delta and Grand Junction. The actual site was a joint selection of the Hydraulics Laboratory and NERC with advice from the Colorado Fisheries Project and USBR project offices in Grand Junction, Colorado. A limited portion of the fiscal year 1992 funds available were used by the Grand Junction Project Office to collect data for the study. The results of the field work are presented below for fiscal year 1993. Most of the funds used in 1993 were FY93 funds.

DEVELOP WORKING RELATIONSHIP WITH USBR HYDRAULICS LABORATORY

One of the objectives of the joint study is to improve working relationships between the USBR and USFWS by an exchange of personal. In the case of this study this was done by considerable joint field work by staff of the Hydraulics Laboratory and NERC.

FISCAL YEAR 1993 ACTIVITIES

The overall work to be accomplished in FY93 using both USBR and USFWS funding was the following:

1. Design and start the one-dimensional flume study.

2. Continue development of field techniques for sampling of the substrate of a gravel-bed river that includes both physical and biological considerations.

3. Continue collection of data for the Gunnison River, CO test site that will be used for the numerical modeling, and for the field test of techniques and models developed in the study.

4. Begin development of a numerical model that can be used in the determination of instream flow needs for the maintenance of substrate habitat in gravel-bed rivers.

The responsibility of NERC was to assist in the flume study with major contributions in the design of the experiments; to assist in the collection of the data for the Gunnison River test site; develop substrate sampling techniques and collect the substrate data for the Gunnison River test site; assist in the collection of field data; and begin the development of numerical models.

The responsibility of the Bureau of Reclamation's Research Division was to conduct the flume tests, assist in conceptual design of numerical modeling, and direct the Gunnison River field study.

The products expected as a result of the FY93 work were:

1. A report on the techniques for sampling of gravel substrates (NERC);

2. A partial data base from the laboratory flume (USBR);

3. A progress report on the Gunnison River field study (USBR and NERC); and

4. An overall end-of-year report on the study (USBR and NERC).

All of the reports were due on 30 September 1993.

GUNNISON FIELD TEST

The field data collection was original expected to be funded equally by both agencies. Unfortunately, the NERC did not receive adequate funding for the field work. As a result, all of the FY93 funding for the field work was from Bureau of Reclamation sources. Field data is required to do the numerical modeling and was a high priority work element for FY93. Field data is needed in order to do both the numerical modeling and flume study. The existence of field measurements is critical for the work planned for FY94 to be accomplished.

LABORATORY FLUME STUDY

Work on the laboratory flume study is progressing. The initial work is on the turbulent structure and on clear water scour.

NUMERICAL MODELING

A limited amount of work has been done on the numerical modeling because of the need to concentrated in the collection of data for the Gunnison River. At the end of the fiscal year work was under way on the adaptation and modification of models used in the Physical Habitat Simulation System to instream flow analysis.

FISCAL YEAR 1994 ACTIVITIES

During fiscal year 1994 the major work for the project was the following:

One-dimensional numerical model.

A complete laboratory flume data base.

A complete year of Gunnison River field data.

In addition, a limited amount of work will have to be done on the hydrologic aspects of establishing flushing flows. Each of the elements of the fiscal year 1994 are outlined below.

ONE-DIMENSIONAL NUMERICAL MODEL

The one-dimensional numerical includes velocity distribution across the channel and in the vertical. The major factor making the model a one-dimensional model is that the water surface is simulated as flat when in fact it is not and the division of water between channels must be done by the user of the model. A two-dimensional model would not assume the water surface is flat and would divide the water between the channels. The model simulates velocities and shear stress. The model was used to calculated a critical discharge in the Gunnison River of 10,600 cfs. The present model is based on elements of version III of the Physical Habitat Simulation System.

LABORATORY EXPERIMENTS

The laboratory experiments resulted in information on clear water scour and on the turbulent structure of the flow. The following work was accomplished during the year.

The bottom of the laboratory test duct was filled with material simulating the gradation analyses of base substrate from the Gunnison River at the Dominguez Flats field test site. Velocity profiles, velocity fluctuations and tractive shears have been measured for steps of mean velocity up to 2-1/4 (ft/s). The upstream substrate material armored with 1 to 3-inch gravel and the downstream test station armored with 1/2-inch to No. 4 sieve material. This reduction of armor size as entrance disturbances dampen and the flow approaches fully developed conditions clearly shows the importance of turbulence in transport capability of flow. The Laser velocity meter was found to be lacking because it could only measure two components. The laser was replaced with a new acoustic doppler velocity meter that measures three velocity components and their fluctuations simultaneously. Clear water tests will continue in step increases up to 10 (ft/s). Next the bed will be replaced with a clean armor. Then a series of tests will begin with a velocity of 10 (ft/s) with fine sediment load. Velocity will be reduced in steps and infiltration of fines into the armor will be observed. Future laboratory experiments will result in additional information on clear water scour, infiltration of fines into armor and turbulence structure of the flow. Other aspects of flushing flow will be studied in the laboratory as work on the numerical modeling progresses.

GUNNISON RIVER DATA COLLECTION

The data collected during FY93 was the minimum needed to do the one-dimensional numerical modeling. The data collected in FY94 is the minimum needed to do the three dimensional modeling. Two sets of profile, measurements were made. One set at a low flow in February and the second set during the high water period in the spring. Substrate samples were obtained at a number of locations along the stream and the substrate mapped at a number of cross sections. Cross sections 1 thru 7, and cross sections 18 and 19 were measured in September 1994. Velocity measurements were made at five cross sections using the standards developed in fiscal year 1993.

All the data are available in the offices of the USBR in Grand Junction. All originals are located in Grand Junction

DEVELOP HYDROLOGIC TECHNIQUES

During the first two years of the project it was found that the sediment load to a stream and the time pattern of the load are important in the establishment of an instream flow requirement. The sediment load data collected by the U.S. Geological Survey for the Trinity River was used to test concepts of using hydrologic information in flushing flow analysis. The results of this analysis suggest sediment balance logic must be used if the sediment transport in the stream is large.

FISCAL YEAR 1995 ACTIVITIES

The planned work for 1995 was the following:

Improvement of the one-dimensional numerical model.

Application of the one-dimensional numerical model.

A report on the Gunnison River field data.

Limited monitoring of the Gunnison River test site.

Accomplishments during fiscal year 1995 were the following:

Improvements in the one dimensional model were made. These improvements were the development of a link between the biological needs of aquatic organisms and the sediment based on a modeling of hydraulics of sediment transport at the stream bed. The object of the modeling is to calculate the size of the sediment that must be removed by flushing in order to have a stream bed with the physical characteristics needed by the aquatic organism.

The improved model was applied to the Gunnison River near Grand Junction, Colorado; the Trinity River below Lewiston Dam in California; and the Williams Fork River in Colorado. The results are in four papers written and published during the year.

The field work during the fiscal year was 1) a survey of the substrate of the river,
2) measurement of high flow discharge and of the water surface profile at the high discharge, and
3) the sampling of bed material after the high flow event of 1995.

A data report with the data collected during the fiscal year has been completed. A paper on the techniques used to do the data collection was presented to a hydraulic conference during the year.

The work plan was modified in FY95 to extend the project into fiscal year 1997. This decision was made in January 1995. The reasons for the adjusted from original plan is because in delays caused work on the flume and a slow start in the development of models. The delay of both the physical and the numerical modeling was caused by the need for the modeling staff to work on the field data collection effort. The original study plan had funds for other staff to do the field data collection and the analysis of the data to the point it could be used in numerical modeling.

IMPROVED TECHNIQUES

The bed material in many rivers is quite variable with considerable quantities of sand on, and among, the gravel and cobbles on the surface of the stream. The bed material can have large sizes in one area and smaller sizes in some other areas. In many situations, sand and fine material must be from the surface of the bars (riffles) and from the pools. In other situations the objective is to remove sand and fines from with in the bed material.

One of the two flushing flow objectives is the removal of fines and sand from the parts of the river that may be used as spawning sites by a fish species or other aquatic animal.

Criteria for flushing of the surface of gravel and cobble rivers were developed in 1986 that used a substrate movement parameter (called beta parameter in 1986). The equation for the substrate movement parameter (ß) is:

$$ß = \frac{R * S_e}{D50_a * (G_s - 1)}$$

where R is the hydraulic radius, S_e is the energy slope, $D50_a$ is the median size of the armour on the bed surface, and G_s is the specific gravity of the armour material.

For removal of fines and sand from the surface of a cobble and gravel stream bed, beta should be at least 0.021.

The improvement in the technology during FY95 was the development of techniques for the calculation of a critical discharge for removal of sand and fines based on the maximum wash load size that must be removed. The maximum sizes is determined on the basis of the biological needs of the aquatic animal.

An other improvement was the refinement of a sediment transport capacity index that has proven useful in investigating impacts of water projects and water management on the ability of a river to move sediment. The sediment transport capacity index (STCI) is calculated using the equation:

$$STCI = \Sigma((Q-QCRT)/QREF)^{b}$$

where Q is the daily discharge, QCRT is a critical discharge, QREF is a reference discharge, and b is the power term in the sediment load vs. discharge equation (2.0 for Gunnison River). The summation is over a period of interest; in this paper the summation period is a water year.

An example of a conclusion made about the Gunnison River using the improved techniques is that the discharge needed to maintain pools in the condition needed by Colorado Squawfish is 226 m^3/s and to maintain bars in the state needed by the Colorado Squawfish for spawning is 480 m^3/s. The frequency of the flows with the capacity to clean the potential spawning bars was 50% for the years up to 1936, in comparison to 12% in the 1968-1993 period. The frequency of flows available to remove sediment from the pools has been reduced from 92% of the years up to 1936 to 46% of the years between 1966 and 1993. The sediment transport capacity index for pool cleaning has been reduced from 58.9 to 10.6, an 82% reduction; and the STCI for bar cleaning reduced from 6.62 to 0.26, a 96% reduction. In 1993 the sediment transport capacity was adequate to remove fines and sand from both pools and riffles. (The STCI for bar flushing was 0.81, and for pool flushing 55.56.) This runoff event did cause flushing of the pools. There was also a change in at least on bar. Measured bulk density in February 1993 was 2.61 kg/m^3 which means few voids existed. The measured bulk density after the 1993 runoff event was 2.08 kg/m^3. The sediment transport capacity needed to clean the bars was zero the previous eight years. The observed scour of the thalweg and the change in bulk density suggest the conclusions of the paper are at least reasonable. There are two problems should temper these conclusions. The first is that the spawning needs of the Colorado Squawfish are poorly understood. The second is that a one-dimensional analysis was used. The spawning needs of the fish should be better understood and a two-dimensional analysis technique used that relates the specific locations in the stream that have the bed conditions needed for spawning with the two-dimensional velocity structure before definitive conclusions can be made. The conclusions from this paper can be used on an interim basis. (The techniques were improved in FY96)

FISCAL YEAR 1996 ACTIVITIES

The planned work for fiscal year 1996 was the following:

Report on the laboratory experiments.

Report the Gunnison River field data and the application of one-dimensional flushing flow models to the river.

Development of a three-dimensional numerical model.

Application of the three-dimensional numerical model.

The primary work planned for FY96 was the completion of a laboratory report and reporting of work on the Gunnison River. The work to develop and apply a three-dimensional modeling will not be done if adequate funding is not received and the models developed to date will not be refined for use by others.

The report on the laboratory experiments is the responsibility of the USBR hydraulics laboratory and is nearing completion. Because the laboratory results are not available, the techniques developed were tested using data measured by the U.S. Geological Survey in the Trinity River watershed. The test strongly indicates the logic and calculation procedures are reasonable.

A data report on the data collected for the Gunnison River in Fiscal Year 1996 was completed.

The major loss in efficiency resulting from the furlough in the November, December, and January; and the needed to test the one-dimensional model using the Trinity River data caused the three-dimensional modeling work not to be completed. The need for a 3-D model still exists and the data is available for the Gunnison River to test the model and help in the development of the model.

The target work for fiscal year 1997 was originally the following:

Report on the three-dimensional model.

Technical report on the whole study.

Summary report.

These will not be done, the papers in-press eliminate the need for either a technical or summary report. The decision has been made by agreement that future work should be considered as a new study under the same project.

The study has accomplished the original objective to develop a new and improved method for determining the streamflows needed to maintain habitat downstream of reservoirs. This new and improved plan is outlined in the following paragraphs.

The improved technique for the calculation of streamflows needed to manage sediment in rivers has three major components:

1) a biological component that determines the objectives of sediment management in the stream,

2) a hydraulic component that determines the hydraulic conditions needed to accomplish the biological goals, and

3) a selection component linking the hydraulic and biological components to determine instream flow needs for the management of sediment.

Biological Component: The objective of the biological component is to determine the biological needs related to the sedimentation processes in a stream. This requires knowledge of the habitat needs of the aquatic animals as related to sedimentation. The task is not a small task. Four examples of sediment related habitat considerations are below:

1) Some species of fish spawn by broadcasting their eggs which settle to the stream bottom and stick to gravel or larger particles where they stay until they hatch; if the stream bed is covered with sand or fines before spawning, or the eggs are covered after spawning, spawning will be unsuccessfully.

2) Other species of fish (for example salmon and trout) dig redds (nests) into the stream bed, deposit eggs, and cover the eggs with gravel. If the bed materials are too large, the redd can not be dug; and if fines are intruded into the stream bed, or cover the stream bed after spawning, incubation may not be successful.

3) Some species of amphibians live in voids within a cobble/boulder stream bed, if these voids are filled with sediment the species can not use the stream as habitat.

4) Mussel adapted to gravel bars may not survive if the bars are covered with sand or fines. The impact on the mussels of the sand and fines can be directly on

the mussels, or on the fish important in mussel reproduction, or on both.

The objective of the biological component is to develop a 'model' of the relationship of sediment to the species of interest. In many cases the 'model' should relate to the total aquatic ecosystem, or an assemblage of aquatic animals, and not a specific species of aquatic animal. Most often the 'model' will specify the sizes of sediment that must not be deposited in, or on the stream bed, or that must be removed by flushing. The channel morphology aspects of the model will often be a need to maintain side channels that can be used as a refugia for small fish.

Hydraulic Component: The objective of the hydraulic component is to determine the hydraulics needed to remove and transport sediment through the stream channel and to maintain the channel morphology as required to meet the needs of the biological 'model'.

If the biological model specifies the size of sediment that must be removed form the stream bed, the maximum size of the sediment to be removed becomes the maximum size of the wash, suspended, or bed load depending on other aspects of the biological model. Equations are available to calculate the maximum size of the sediment load.

The equations used to calculate the maximum size of the wash (dmaxw), suspended (dmaxs), and bed load (dmaxbl) are:

$$(1) \quad dmaxw = R\ S_e/(0.56\ (G_s-1))$$

$$(2) \quad dmaxs = R\ S_e/(0.28\ (G_s-1)$$

$$(3) \quad dmaxbl = ((R\ S_e/(0.018\ (G_s-1))^{2.85})\ (d50_a{}^{-1.85})$$

where R is the hydraulic radius, S_e is the energy slope, G_s is the specific gravity of the particles, and $d50_a$ is the median size of the stream bed armour. The equation for the maximum size of the bed load should only be used when the median size of the bed load is less than the median size of the armour and the objective is to keep material moving through the stream when the armour is relatively stable. The equations used in the calculation of the median size of the bed load (d50bl) is:

$$(4) \quad d50bl = (R\ S_e/(0.046*(G_s-1))^{2.85} * (d50_a{}^{-1.85})$$

when the median size of the bed load is less than the median size of the armour. The bed load equations are for the calculation of the sizes of the bed load during flushing of the bed material and not for general movement at higher streamflows.

In previous work a stream substrate movement parameter, ß, was used to determine the flushing flow needs in a stream. The equation for the substrate movement parameter is:

(5) $ß = R\ S_e/(G_s - 1)\ D50_a$

where R is the hydraulic radius, S_e is the energy slope, G_s is the specific gravity of the bed material (substrate), and $D50_a$ is the median size of the bed armour material.

The selection of the values of the substrate movement parameter needed to determine a flushing flow need was done using data obtained during bed load transport research in Oak Creek, Oregon. The Oak Creek data indicated the value of ß required for removal of fines and sand from the surface of a gravel bed river (surface flushing) is 0.021; and for removal of material from with in the substrate (depth flushing) 0.035. An important assumption is that the Oak Creek results could be generalized to other rivers.

The use of a surface flushing ß of 0.021 should be used if the 'biological model' does not give the size of sediment to be removed. If the sizes of sediment to be removed are known the equations for ß are:

(6) $ß = 0.56\ (dt_w/d50_a)$
(7) $ß = 0.28\ (dt_s/d50_a)$
(8) $ß = 0.018\ (dt_{bl}/d50_a)^{0.35}$

where dt is the target size of sizes of sediment to move specified in the biological model. The subscript w is for wash load, s for suspended load, and bl is for bed load. Note that the substrate movement parameter is <u>always</u> the dimensionless shear stress calculated using the median (d50) size of the stream bed armour.

The undesirable sediment may be moved either as wash, suspended, or bed load. The selection of the appropriate type of load to use in the analysis is based on the 'biological model'. Sometimes the biological model will indicate certain sizes should be moved in one state (i.e. wash load) and other sizes moved in another state (i.e. suspended or bed load).

<u>Selection Component:</u> The selection component combines the results from the maximum size analysis and the biological analysis to define the instream flows needed to manage the sediment flows through the river so as not to have a detrimental impact on the aquatic system. The design of the selection process depends on the nature of the aquatic ecosystem. In many cases there will be a critical period during which fine sediment or sand should not be deposited on the stream bed and a need to remove sand and fines deposited on the stream bed. For salmon and trout there is

a needed to flush sand and fines from within the stream bed. For walleye perch and paddlefish there is need to keep fines from settling on the eggs deposited on the stream bed during incubation.

The development of criteria for the selection of instream flow needs for flushing is the critical component of the process. If the aquatic ecosystem is not understood, or the goals of aquatic ecosystem management not know, the selection component can not be designed. If the selection component can not be designed, an instream flow need can not be determined.

Application to the Gunnison River: The improved technique was used to determine the instream flows needed in the lower Gunnison River in western Colorado (USA) to improve the sediment related aspects of the habitat of Colorado Squawfish. The Gunnison River is a reasonably large river with a mean discharge of 73 cubic meters per second (cms) located in Southwestern Colorado. The lower reach of the river is habitat for Colorado Squawfish, an endangered species. The flows of both sediment and water in the river have been modified by the construction of reservoirs and by major diversions for irrigation. The reservoirs have reduced the capacity of the river to cleanse the bed material of fines and sand with the result that there has probably been an increase in fines and sand on, and within, the stream bed. There are three types of bed material in the lower Gunnison River: 1) material forming the protective surface of the river bed (armour), 2) material making up most of the stream bed (substrate), and 3) material on the surface of the armour at low flows (ephemeral bed material). Numerical models which consider the three types are used to obtain the flushing flow needs. The flows needed to maintain the spawning habitat for the Colorado Squawfish by removing fines and sand from the bars (riffles) are 430 cms; the flows needed during the spawning period to keep fines from settling on the cobbles in the spawning areas is 25 cms; and the flows needed to remove sand and fines from the pools used by the adult fish is 226 cms. These flushing flows are probably not required each year but they are required periodically; the maintenance flow is needed every year. The index to the capacity of the river to transport sediment (Sediment Transport Capacity Index, STCI) presented in the sections was used to give some idea of the changes in the ability of the river to meet the needs obtained by using the hydraulic simulation models. The frequency of flows available to remove sediment from the pools has been reduced by reservoirs from 82% of the years up to 1936, to 46% of the years between 1966 and 1995. The frequency of the flows with the capacity to clean the potential spawning bars was 57% for the years up to 1936, in comparison, the frequency was 14% in the 1968-1993 period. The average annual STCI for pool cleaning has been reduced from 122 to 28, an 82%

reduction; and the STCI for bar cleaning reduced from 31.1 to 3.3, a 90% reduction. At present an analytical technique for estimating the frequency of flushing flows has not been developed but field observations and a review of the historic pattern of sediment transport capacity suggests the frequency should be about once in every two or three years. The travel time in the river was used to determine the length of time a flushing flow must occur is at least 4 days.

PRODUCTS

The planned products from this project are 1) reports, 2) papers in the engineering and scientific literature, and 3) computer programs along with the documentation on how to use the programs.

The products listed below are completed reports and analytical program documentation. Products in progress are not listed.

The progress report (this report) is an accumulative report and is not listed as a product for any year. There has been a progress report for each year.

Fiscal Year 1992

Johnson P.L. and R.T. Milhous. 1992. Field Site Selection for the Flushing Flow Cooperative Research Study. Joint Report of the Hydraulics Division, USBR and National Ecology Research Center, USFWS. Denver and Fort Collins, CO. v.p.

Fiscal Year 1993

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Johnson, P.L. and R.T. Milhous. 1993. Joint Study Plan: Improve Analytical Techniques for Restoration and Management of Habitat in Western Gravel and Cobble Bed Rivers. Joint Study Plan of the Hydraulics Division, USBR and National Ecology Research Center, USFWS. Denver and Fort Collins, CO. v.p.

Flushing Flow Study Team. 1993. Field Data Report for FY93. Hydraulics Division, USBR and National Ecology Research Center, USFWS. Denver and Fort Collins, CO. pp38.

Fiscal Year 1994

Milhous, Robert T. 1994. Flushing Flows for the Water Manager. in Fontane, Darrell G. and Harry N. Tuvel ed. Water policy and Management: Solving the Problems. American Society of Civil Engineers. New York, NY. pp226-229.

Milhous, Robert T. 1994. Sediment Balance and Flushing Flow Analysis: Trinity River case Study. in Morel-Seytoux, Hubert J. ed. Proceedings of American Geophysical Union Fourteenth Annual Hydrology Days. Hydrology Days Publications. Atherthon, CA. pp281-292.

Milhous, Robert T., Russell A. Dodge, and Perry L. Johnson. 1994. Bed Material and Numerical Modeling in a Gravel/Cobble Bed Stream. in Cotroneo, George V. and Ralph R. Rumer eds. Hydraulic Engineering '94. American Society of Civil Engineers. New York, NY. pp1055-1059.

Milhous, Robert T. 1994. On Habitat Simulation in Mountain Rivers. in Cotroneo, George V. and Ralph R. Rumer eds. Hydraulic Engineering '94. American Society of Civil Engineers. New York, NY. pp850-854.

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