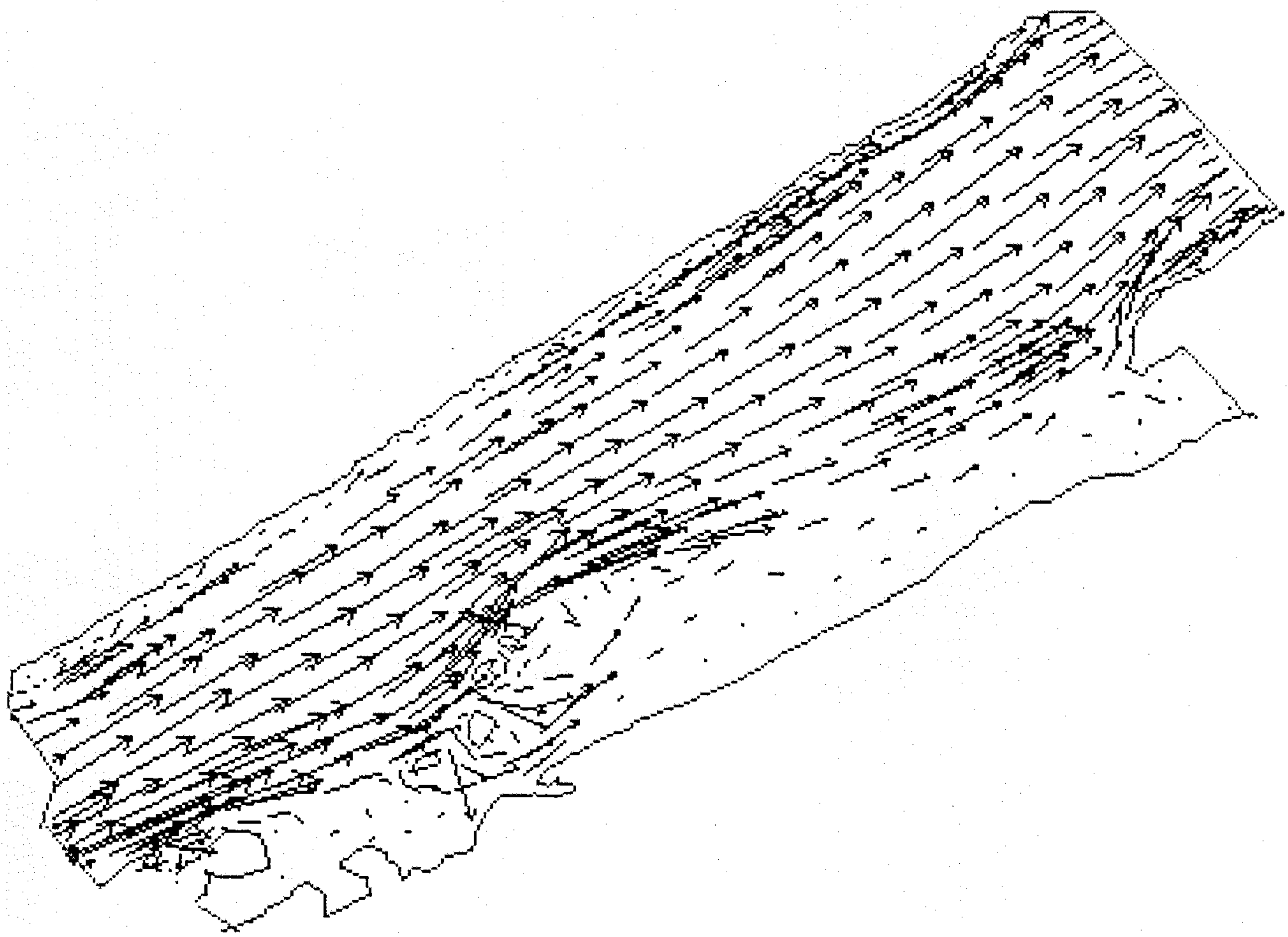
Use of Two Dimensional Hydrodynamic Modeling To Evaluate Channel Rehabilitation in the Trinity River, California, U.S.A.



Fish and Wildlife Service
U. S. Department of the Interior

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Cover diagram: R2D_Hab © velocity vector out put for a hypothetical channel rehabilitation of the Trinity River at 35.31 m^3/s.

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Use of Two Dimensional Hydrodynamic Modeling To Evaluate Channel Rehabilitation in the Trinity River, California, U.S.A.

BY

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ABSTRACT

The Physical Habitat Simulation System (PHABSIM) has been used extensively to predict habitat (Weighted Usable Area) (WUA) changes due to changes in discharge from Trinity Dam. During the late 1980's flow-habitat relationships from PHABSIM initiated pilot channel rehabilitation projects intended to increase salmon habitat. A 12-year flow evaluation of the Trinity River recommends increased flows and channel modifications for habitat rehabilitation. The PHABSIM is limited to predicting changes in WUA due to changes in discharge. Two-dimensional modeling can predict changes in WUA resulting from changes in flow and changes in channel morphology. A preliminary study of the utility of the River_2D© modeling system (Steffler and

Sandelin1998) for evaluating changes in WUA due to channel rehabilitation in the Trinity River was conducted. Model data collection, mesh construction, calibration, and validation were conducted for a rehabilitated and a control site. Chinook salmon (*Oncorhynchus tshawytscha*) location and density was significantly correlated with habitat suitability predictions at both sites. Predicted chinook and coho salmon (0. *kisutch*) and steelhead (0. *mykiss*) fry WUA was higher at the rehabilitation site. Juvenile chinook and coho salmon WUA was increased by rehabilitation at higher flows. The control site model was used to predict WUA based on hypothetical channel morphology. Two-dimensional modeling appears to be a useful tool for evaluating habitat changes in the Trinity River.

INTRODUCTION

The Physical Habitat Simulation System (PHABSIM) component of the Instream Flow Incremental Methodology (IFIM) has been used extensively to predict habitat (Weighted Usable Area) (WUA) changes due to changes in discharge from Trinity Dam (U.S.F.W.S et al. 1998). The PHABSIM predicts depth and velocity across a channel and, combined with habitat suitability, calculates WUA (a habitat index) (Bovee 1982, Milhous et al. 1989). The PHABSIM operates under the assumption that, if physical habitat is a limiting factor, the quality and quantity of available habitat (i.e. WUA) for a limiting life stage during a limiting flow event is directly related to fish population levels. Results of PHABSIM analyses during the 1980's suggested that chinook salmon (*Oncorhynchus tshawytscha*) fry habitat capacity was the population limiting factor in the Trinity River

(U.S.F.W.S 1994). Between 1989 and 1993 the Trinity River Restoration Program constructed 9 pilot bank rehabilitation projects to increase fry rearing habitat (U.S.F.W.S. 1994). The PHABSIM was also used to determine the effect of rehabilitation on WUA (Gallagher 1999, 1995). The 12-year flow evaluation of the Trinity River recommends the construction of up to 43 more bank rehabilitation sites and increased flows to rehabilitate the river and increase salmon populations (U.S.F.W.S et al. 1998).

Leclerc et al. (1995) suggests the IFIM needs to be improved to more reliably predict the effects of altering fish habitat. They suggest that two-dimensional hydrodynamic modeling may overcome some of the limitations of PHABSIM, including accurately representing complex habitats (Railsback 1999). The U.S.F.W.S et al. (1998) state that two-dimensional modeling may be an appropriate tool for adaptive management of the Trinity River. While PHABSIM is limited to predicting changes in WUA due to changes in discharge, two-dimensional modeling can predict changes in WUA resulting from changes in flow and changes in channel morphology. The purpose of this study was a preliminary examination of the utility of the River_2D© modeling system (Steffler and Sandelin 1998) for evaluating changes in WUA due to channel rehabilitation in the Trinity River. We collected field data, developed calibrated models, and validated the models for one rehabilitated and one control site. Predicted habitat suitability was compared to chinook salmon density and location for both sites at one flow. Predicted salmon WUA were compared between sites. To further examine the predictive ability of the model, the control site model was modified to represent a hypothetical channel rehabilitation project.

STUDY AREA

The Trinity River watershed drains approximately 7,679 km^2 in Trinity and Humboldt counties of northwestern California and is a major tributary to the Klamath River (Fig. 1). Lewiston Dam at river km 180 is the upstream limit to salmon migration. The upper segment of the river, between Lewiston and the North Fork Trinity River, is the most important for salmonid production (U.S.F.W.S. 1994). This segment has a narrow channel with steep heavily vegetated banks and sand, gravel, and cobble substrate. One 320 m long rehabilitation site at river km 147 and one 204 m long control site at river km 149 (Gallagher 1999) in the segment between the North Fork Trinity and Lewiston Dam were selected for this study.

METHODS

A stage discharge relationship at the downstream site boundary, flow distribution at the upstream site boundary, and maps of bathymetry and dominant substrate are the physical data required for two-dimensional hydrodynamic modeling (Leclerc et al. 1995). Stage discharge relationships were developed at the top and bottom of both sites following the procedures in Trihey and Wegner (1981). During August 1997 standard surveying techniques were used to survey the topography of both sites. A site-specific coordinate system (north, east, and elevation) was established for each site and the entire site was surveyed on a 6.3-m grid. Point density was increased in areas of rapid topography or substrate change and around dominant features such as boulders and large wood. Dominant substrate was visually estimated using a modified Wentworth scale (Platts et al. 1983) for each point. Water surface elevations, depths, and velocities were measured at a number of points for model calibration (Tables 1 and 2).

The survey data were used to create bed topography files for input into the River-2D modeling system following the procedures of Steffler (1998). The bed topography file thus created was input into the R2D_Mesh mesh generation program to generate a finite element mesh for input to the R2D_Flow (Depth Averaged Hydrodynamic Model, Steffler 1997). The mesh was run to steady state in R2D_Flow (rehab. site net outflow = -0.9, uc = 0.0004; control site net outflow = 0.005, UC = 0.0004). The resulting output file was input into the R2D_Hab program (Steffler and Sandelin 1998) to examine calibration details and calculate WUA. Model predicted water surface elevations, depths and velocities were compared to field data for.calibration. The calibrated mesh files (calibrated at 15.8 m^3/s) for both sites were run to steady state for flows of 35.4, 45.0, and 61.4 m^3/s. Chinook and coho (0. *kisutch*) salmon and steelhead (0. *mykiss*) fry (< 50 mm) and juvenile (> 50mm) WUA were calculated in R2D_Hab using Trinity River specific habitat suitability criteria (Hampton 1988).

During April 1999 divers snorkeled up both banks of each site marking the location of all fish observed. Fish species, size, number in school, and associated cover were recorded for each location. Standard surveying techniques were used to establish the point coordinate of each fish observation relative to the grid system used to develop the models for each site. The calibrated River_2D models for both sites were run at 23.45 m^3/s, the discharge during the fish location surveys. Fry chinook salmon were the most abundant species and life stage during April 1999. Predicted habitat suitability was determined for each fish (or school) location in R2D_Hab. Chinook salmon fry density at each location was compared to predicted habitat suitability using Peterson product correlation in Statgraphics (Manugistics 1997).

To examine the model's predictive ability, the calibrated bed file for the control site was modified in R2D_Bed to resemble a rehabilitation site. The riparian berrn along one bank was removed, the river widened and the sand substrate was replaced with a cobble bar. The top and bottom of the site were not altered so that the stage discharge relationship would remain unchanged. The resulting bed file was treated as above to generate a mesh, run to steady state, and calculate WUA.

RESULTS

The predicted and measured depths, velocities, and water surface elevations were not significantly different (Tables 1 and 2). For the control site, the differences between predicted and measured depths and velocities were c 10%. For the rehabilitation site, the differences between predicted and measured depths and velocities were < 18%.

Chinook salmon fry densities were significantly correlated with model predicted habitat suitability at the rehabilitation site ($r = 0.29$, $p = 0.049$, Fig. 2) and at the control site ($r =$

0.41, p = 0.038, Fig. 2b). Areas with higher numbers of chinook salmon fry had higher predicted habitat suitability values.

The rehabilitation site had a higher percentage of chinook and coho salmon and steelhead fry WUA (Figs. 3a-c). The greater WUA at the rehabilitation site was maintained as flows increased. Chinook and coho salmon juvenile WUA was lower at the rehabilitation site at 15.8 and 35.4 m^3/s and greater at 61.4 m^3/s (Figs. 4a, b). Steelhead juvenile WUA was lower at the rehabilitation site for all flows examined (Fig. 4c). Fry habitat areas at the rehabilitation site generally migrated up the bank with increased flow (Appendix A). At the control site, habitat bands were constricted and became disconnected as flow increased (Appendix B).

The Rived-D modeling system, specifically R2D_Bed and R2D_Mesh, was capable of developing an input mesh and modeling WUA for a hypothetical channel rehabilitation based on the original control site data (Fig. 5). The hypothetical channel rehabilitation increased chinook and coho salmon fry WUA (Figs. 2a, b). The increases were maintained as flows increased. Steelhead fry WUA was increased at lower flows by the hypothetical rehabilitation (Fig. 2c). Chinook and coho salmon juvenile WUA was increased by the hypothetical rehabilitation (Figs. 4a, b). Steelhead juvenile WUA was increased by the hypothetical rehabilitation at higher flows (Fig. 4c). The predicted WUA for the hypothetical rehabilitation generally followed the trends of the control site including habitat constriction and disconnection as flows increased (Figs. 3, 4, Appendix C).

DISCUSION

The model predicted and field measured data differences for the control and rehabilitation sites were within the ranges reported by Tarbet and Hardy (1996) and Leclerc et al. (1995). Water surface elevations predicted by PHABSIM are considered acceptable if they are within 3mm of measured elevations (Bovee 1996). The River2_D models of the rehabilitation and control sites predicted water surface elevations within this range (Tables 1 and 2). The PHABSIM predicted depths and velocities are considered acceptable if they differ by less than 10% (Bovee 1996). Predicted and measured depths and velocities at the rehabilitation site differed on average by 18%. This was likely due to the small sample size of the calibration data set (n = 13, Table 2). These differences could also have been due to incomplete characterization of the spatial domain by the finite element mesh. Tarbet and Hardey (1996) attributed large differences in predicted and measured depths and velocities to differences between their finite element mesh and the measured channel topography. They found that differences were greatest in areas of complex channel topography. Gallagher (1999) states that rehabilitation sites on the Trinity River are more diverse than control sites which, in part, is due to increased channel complexity.

The U.S.F.W.S. (1990, 1991) found significant relationships between PHABSIM predicted chinook salmon fry and juvenile WUA and fish density at the cell level along transects in the Trinity River. Cells with higher predicted WUA had more fish. Gallagher (unpublished) found significant relationships between chinook salmon fry and juvenile density and PHABSIM predicted WUA at the mesohabitat level in the Trinity

River. Mesohabitats with higher predicted WUA had more fish. The results presented here suggest that significant relationships exist between chinook salmon density and habitat suitability at the microhabitat, mesohabitat and the site levels predicted using the River_2D modeling system. While the control site was a single mesohabitat (i.e. a run), the rehabilitation site included three mesohabitat types (a pool, a run, and a riffle). Two-dimensional modeling can predict WUA for these large areas consisting of many mesohabitat types, thus allowing a more quantitative evaluation of spatial and hydraulic factors potentially controlling fisheries resources (Hardy 1998). The significant relationship between WUA and fish density provides a measure of validation for the River_2D models of these two sites on the Trinity River.

Gallagher (1999) found that channel rehabilitation in the Trinity River significantly increased WUA for chinook salmon and steelhead fry at flows of 32.3 and 60.9 m3/s. Only one control and one rehabilitation site were considered in this study, so statistical comparisons were not possible. However, the trends in WUA shown by two-dimensional modeling are similar to Gallagher (1999). The U.S.F.W.S (1997) state that rehabilitation sites in the Trinity River benefit young-of-the-year salmon because they allow bands of habitat area to migrate up the bank as flows increase, whereas habitat bands in the vegetation encroached channel constrict with increased flows. The results of the two-dimensional modeling demonstrated this effect (Appendices **A** and B). Juvenile WUA, in general, was not shown by two-dimensional modeling to increase as a result of rehabilitation. This'is similar to findings of Gallagher (1999) and is likely a result of juvenile fish being able to tolerate areas with higher velocities.

Chinook fry WUA predicted using the River-2D modeling system differed from that predicted by PHABSIM (Gallagher 1995) for the rehabilitation site (Fig. 6). Tarbet and Hardy (1996) found little difference between PHABSIM and two dimensional model WUA predictions when transects were spaced < 25 m apart. Their study involved different species in a smaller river and used velocity output from two-dimensional models as input to PHABSIM. The difference between PHABSIM and the River-2D modeling of the rehabilitation site may be because the site changed between 1995 (PHABSIM) and 1997 (2D). The differences may also be due to how the two models predict and calculate WUA. The PHABSIM is limited by transect spacing and cell size and uses transect weighting to estimate the area each transect represents. This method treats each cell as a rectangle (Fig. 7) which can potentially underestimate slow edge water areas used by fry. In contrast, the R2_D model calculates WUA for an entire site using bed topography to predict depths and velocities and can estimate these values for irregular channel features (Leclerc et al. 1995, Tarbet and Hardy 1996), including edge areas important to fry (Fig. 5, Appendices A-C). In addition, some calibration problems associated with PHABSIM (Railsback 1999) are potentially avoided with the two-d approach.

The River-2D model system, especially the R2D_Bed program, was useful for creating a hypothetical channel rehabilitation site model from the control site data. Habitat indices can be predicted for various flows and complex channels, an advantage over PHABSIM. This model has utility for the adaptive management (U.S.F.W.S. et al. 1998) of the Trinity River. An approach similar to that undertaken for this study could be used to evaluate 'habitat changes from potential future rehabilitation construction design alternatives before any ground is moved. In addition, this methodology can be used to collect pre-project data for monitoring and post project evaluation as well as feedback for adaptive management. Data collection is compatible with potential geomorphic and biological monitoring and therefore may be more cost effective than other methods. The use of survey grade GPS (B. Mendenhall, California Department of Water Resources, Red Bluff, CA personal communication) and Acoustic Doppler Current Profilers as well as other equipment and techniques (Hardy 1998) will greatly speed up field data collection. However, the amount of detail required to accurately define the bed topography in order to detect changes in WUA due to rehabilitation, for large sites (> 500 m), may exceed our current computing ability. It is likely that computing ability will increase in the next few years. Habitat suitability criteria may require further refinement and development for species found in the Trinity River. The River_2D modeling system appears to be a useful tool for evaluating current and future rehabilitation on the Trinity, as well as, other rivers.

ACKNOWLEDGEMENTS

I thank Charlie Chamberlain, Jay Glase, Polly Taylor, and Rick Quihillalt , U.S. Fish and Wildlife Service, Arcata CA for assistance with field data collection, Mark Card, U.S. Fish and Wildlife Service, Sacramento, and Terry Waddle, U.S. Geological Service Fort Collins, CO for assistance with modeling. Jay Glase and Mark Card provided helpful comments on the manuscript.

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Table. 1. Average, minimum, maximum, SD, t-values and p-values for the difference between measured and predicted water surface elevations (WSE), depths, and velocities for the rehabilitation site.

	Average	n	Min.	Max.	S. D.	t-value	p-value
WSE (m)	0.002	11	0.03	0.05	0.02	-0.27	0.79
Depth (m)	0.03	13	-0.22	0.43	0.14	0.67	0.50
Vel. (m/s)	0.06	13	-0.11	0.32	0.12	1.26	0.21

Table. 2. Average, minimum, maximum, SD, t-values and p-values for the difference between measured and predicted water surface elevations (WSE), depths, and velocities for the control site.

	Average	n	Min.	Max.	S. D.	t-value	p-value
WSE (m)	-0.0005	10	-0.04	0.10	0.04	-0.02	0.98
Depth (m)	0.06	45	-0.27	0.58	0.15	0.78	0.43
Vel. (m/s)	0.07	45	-0.50	0.53	0.15	1.77	0.08

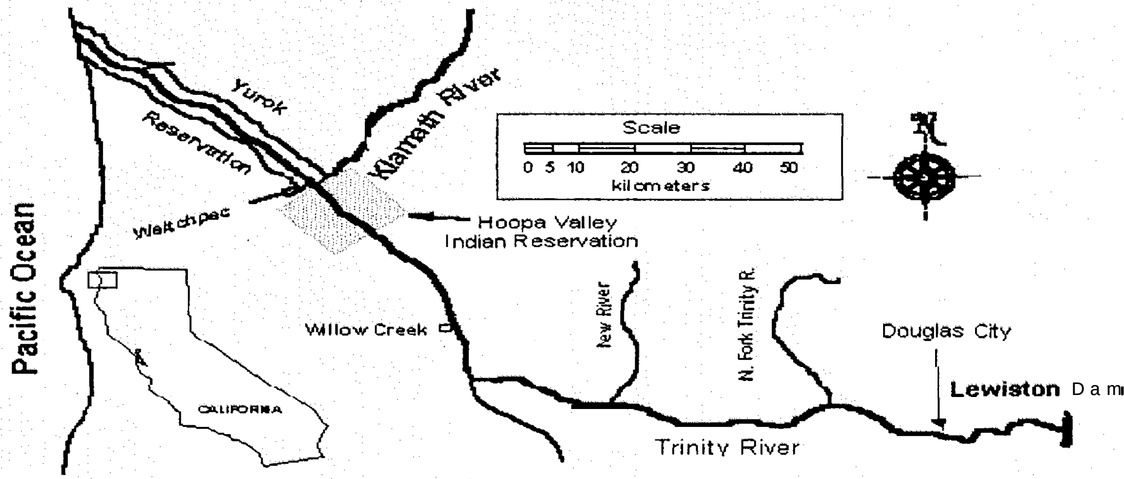
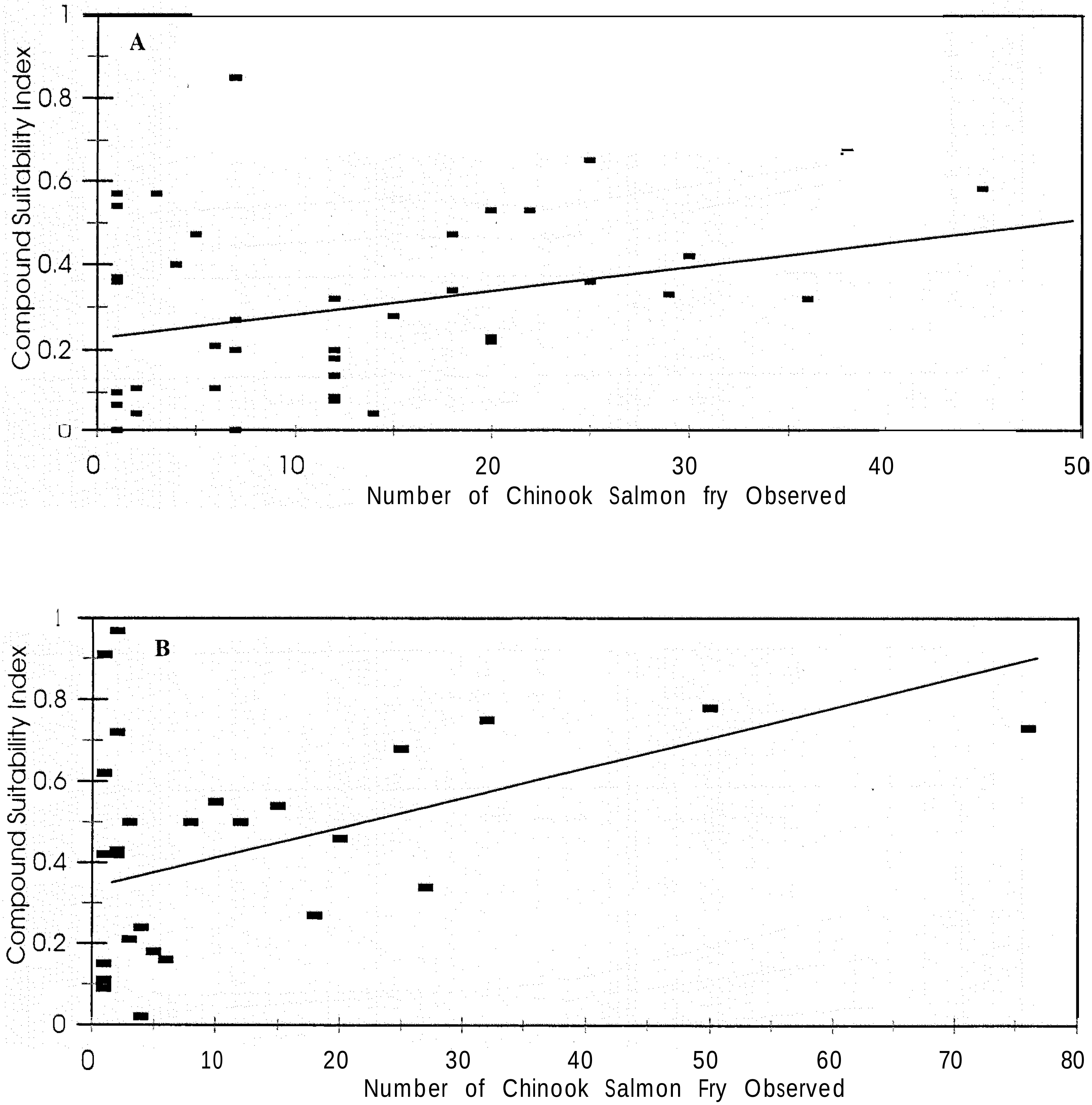


Fig. 1. Location of study sites on the Trinity River in California.



Fig, 2. Scatter plot of the number of chinook salmon fry observed versus compound suitability for each observation. Thin line is the fitted regression. A). Rehabilitation site, n = 44. B). Control site, n = 29.

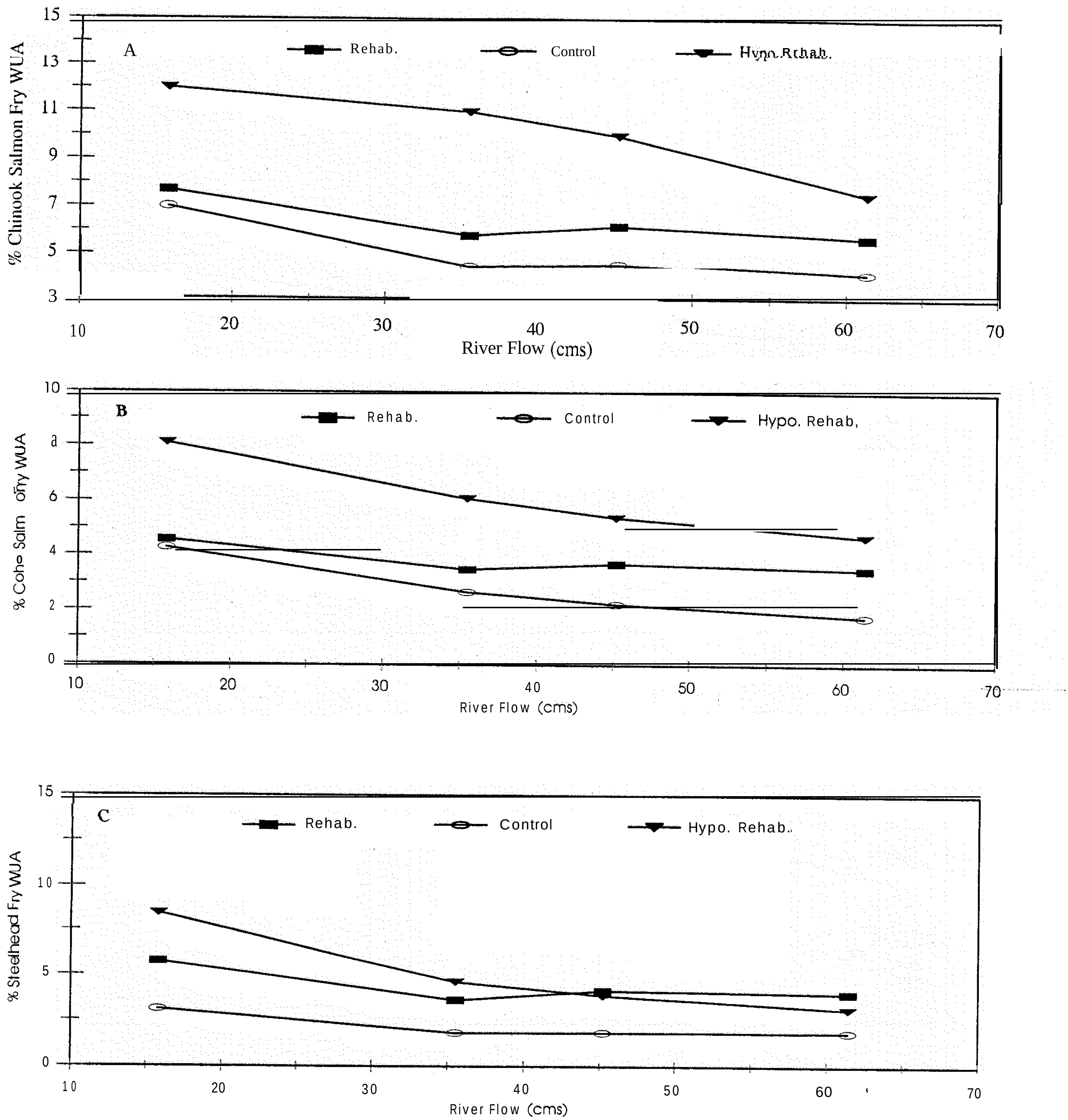


Fig. 3 . Percent salmonid fry WUA for the rehabilitation, control, and hypothetical rehabilitation of the control site at four flows. A). Chinook salmon. B). Coho salmon. C). Steelhead.

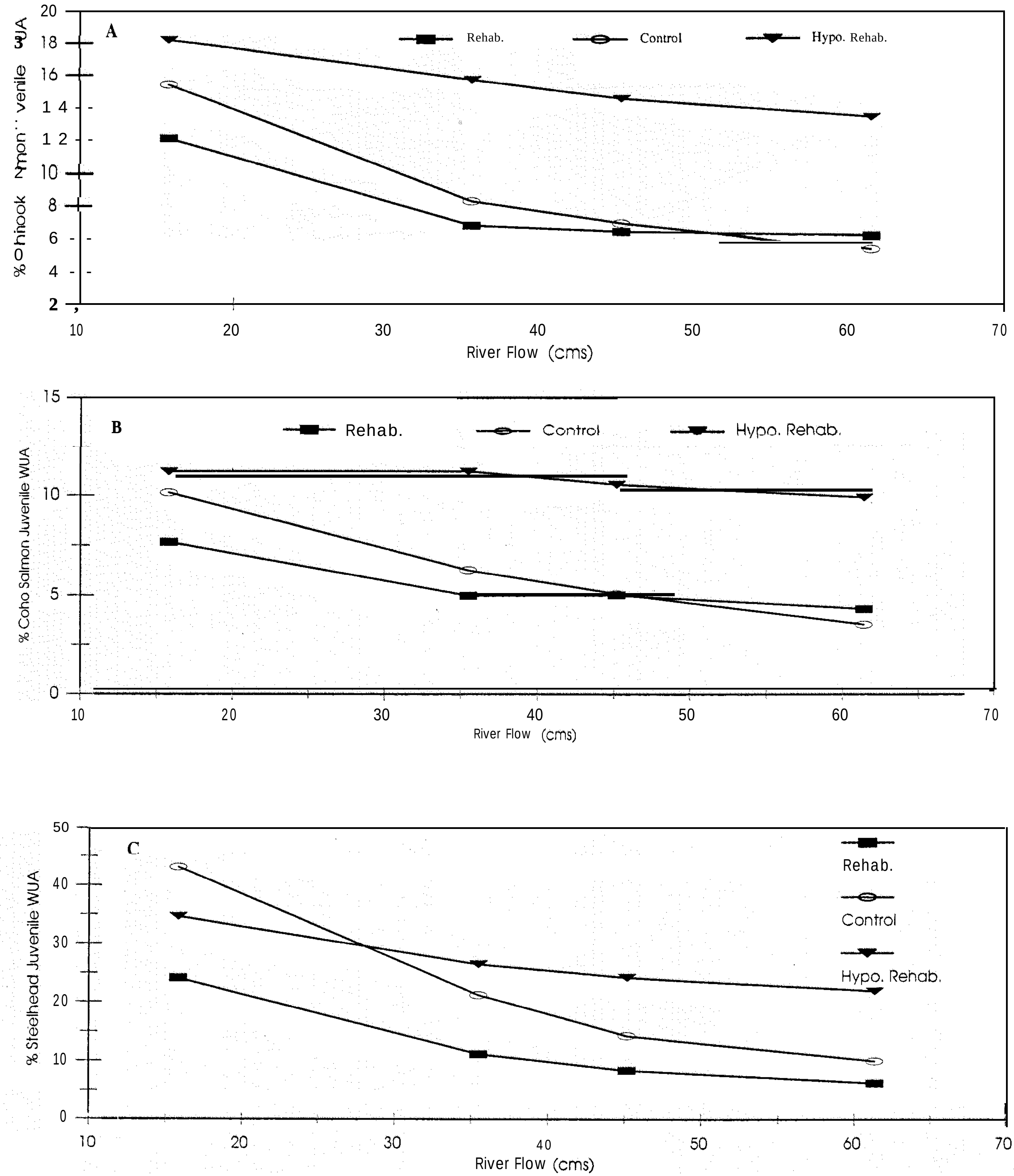


Fig. 4. Percent salmonid juvenile WUA for the rehabilitation, control, and hypothetical rehabilitation of the control site at four flows. A). Chinook salmon. B). Coho salmon. C). Steelhead.

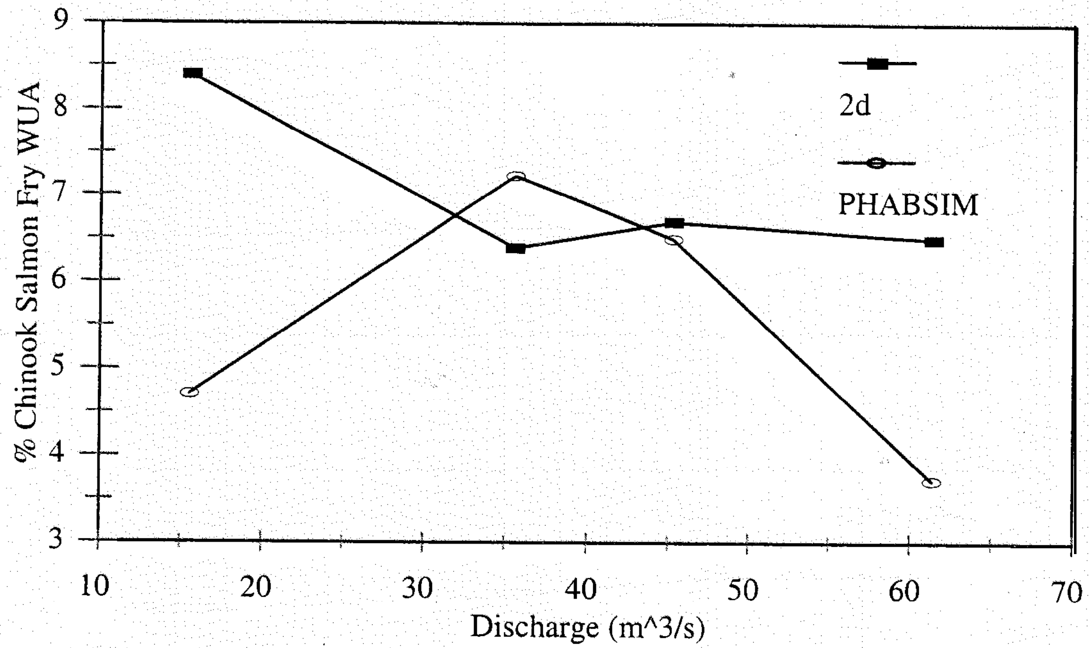


Fig. 6. River_2D and PHABSIM predicated percent chinook salmon fry WUA for the rehabilitation site at 4 flows.

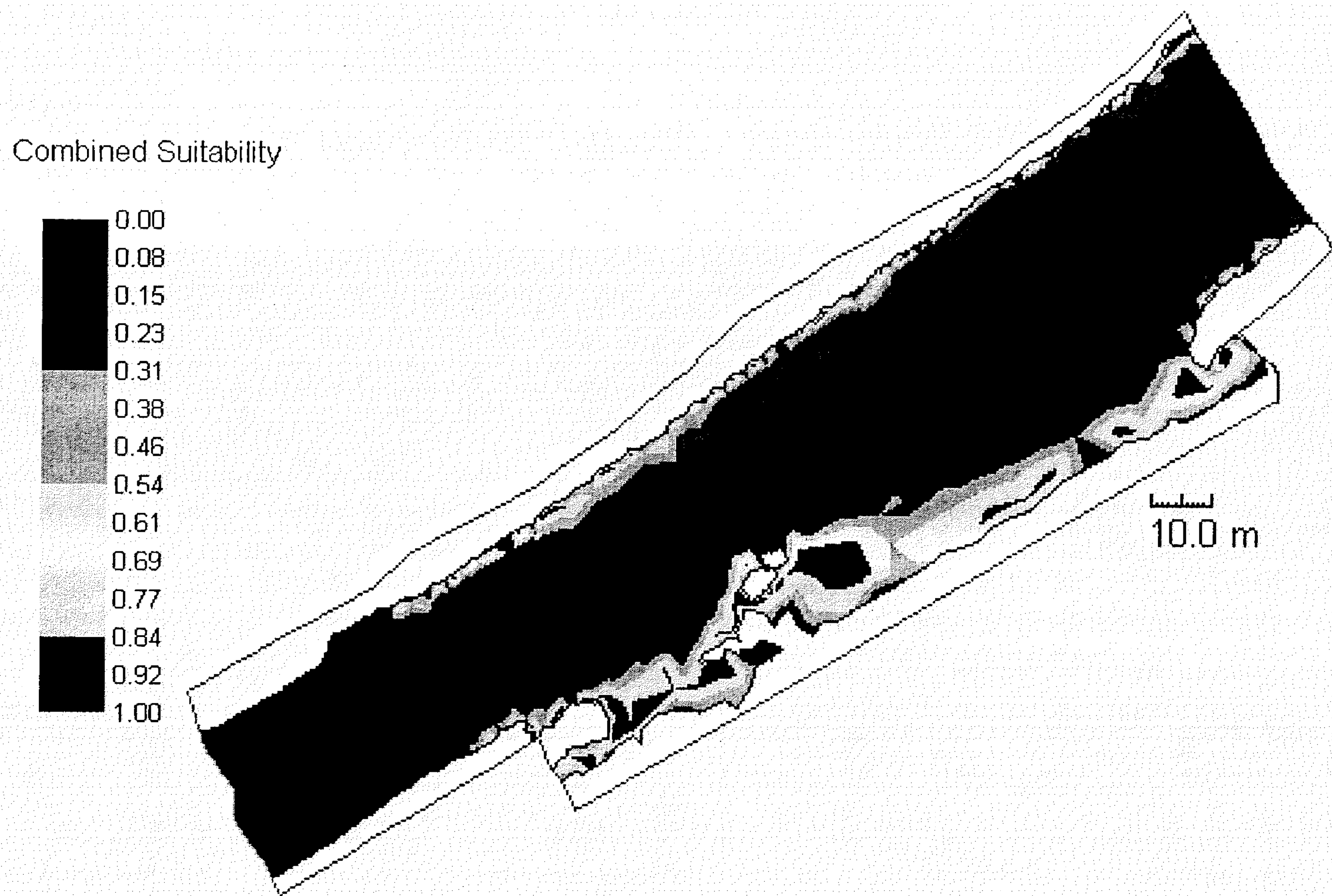


Fig. 5. Chinook salmon fry compound suitability for a hypothetical rehabilitation of the control site at a flow of 15.8 m^3/s. Arrow indicates flow direction.

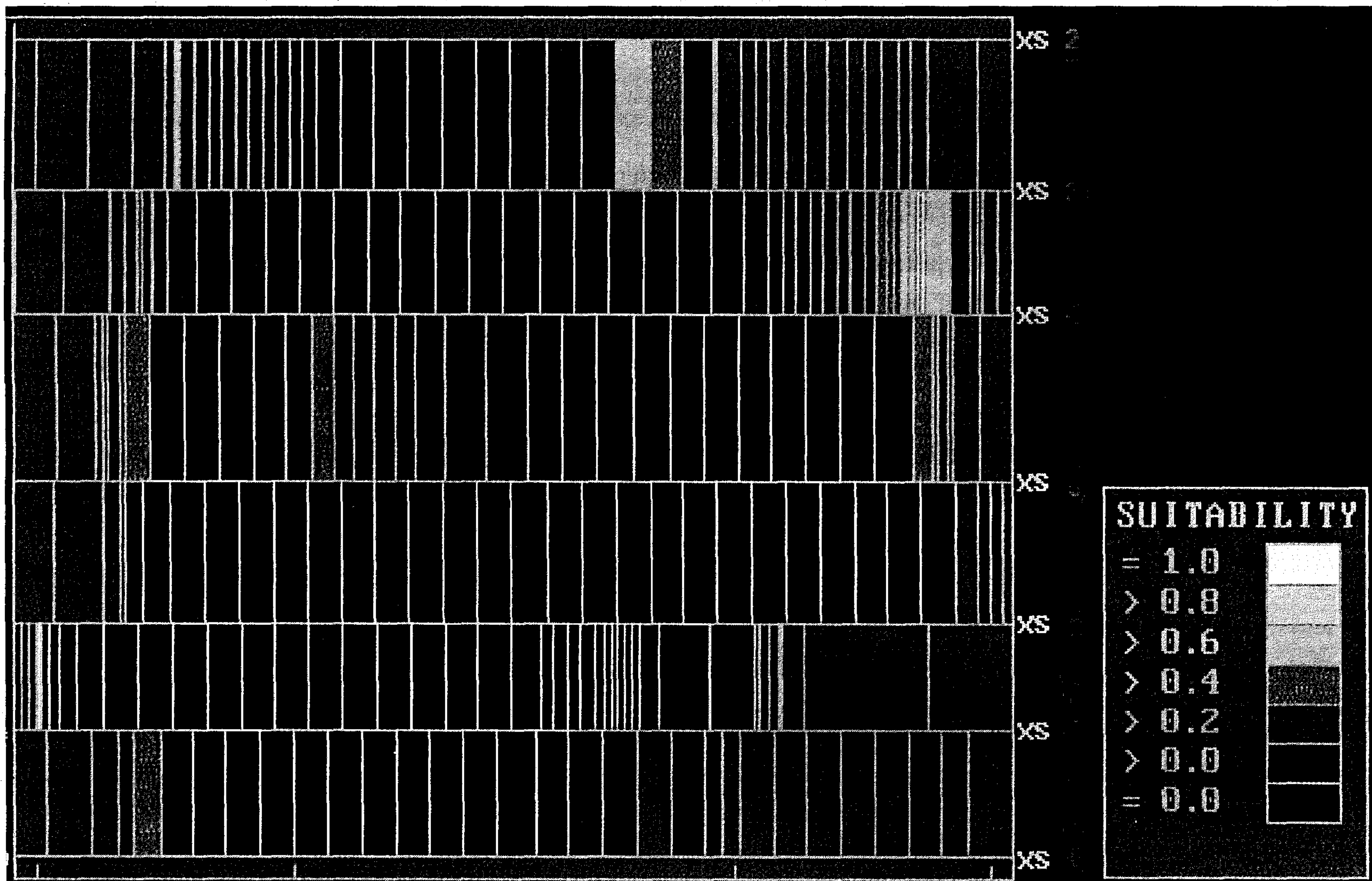


Fig. 7. A RHABSIM (Payne 1995) representation of chinook salmon fry compound suitability for the rehabilitation site at a flow of 15.8 m^3/s.

APPENDIX A

Chinook Salmon Fry Compound Suitability for
the Rehabilitation Site

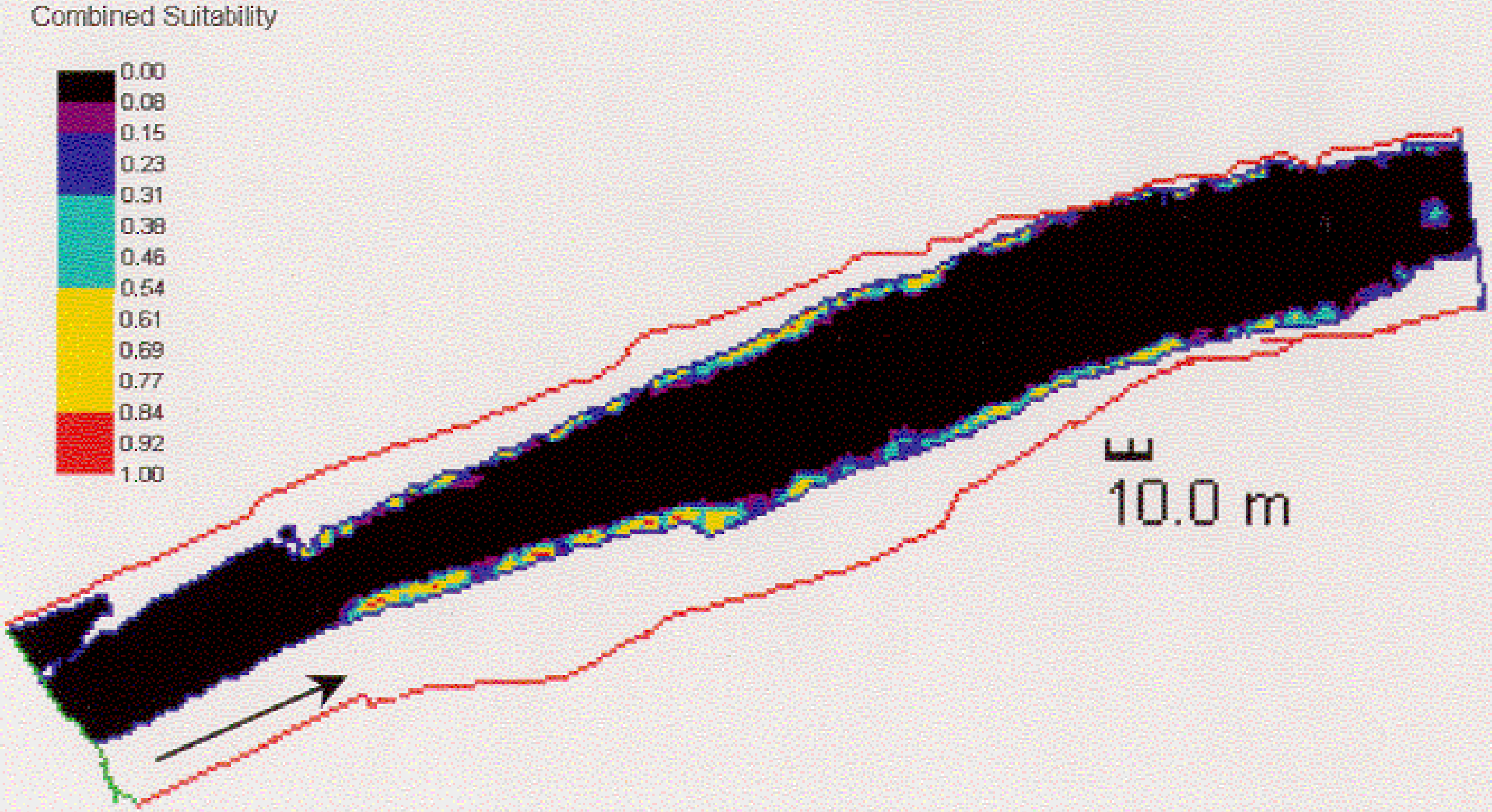


Fig. A 1. Chinook salmon fry compound suitability at the rehabilitation site. Arrow shows flow direction, flow is 15.8 m^3/s.

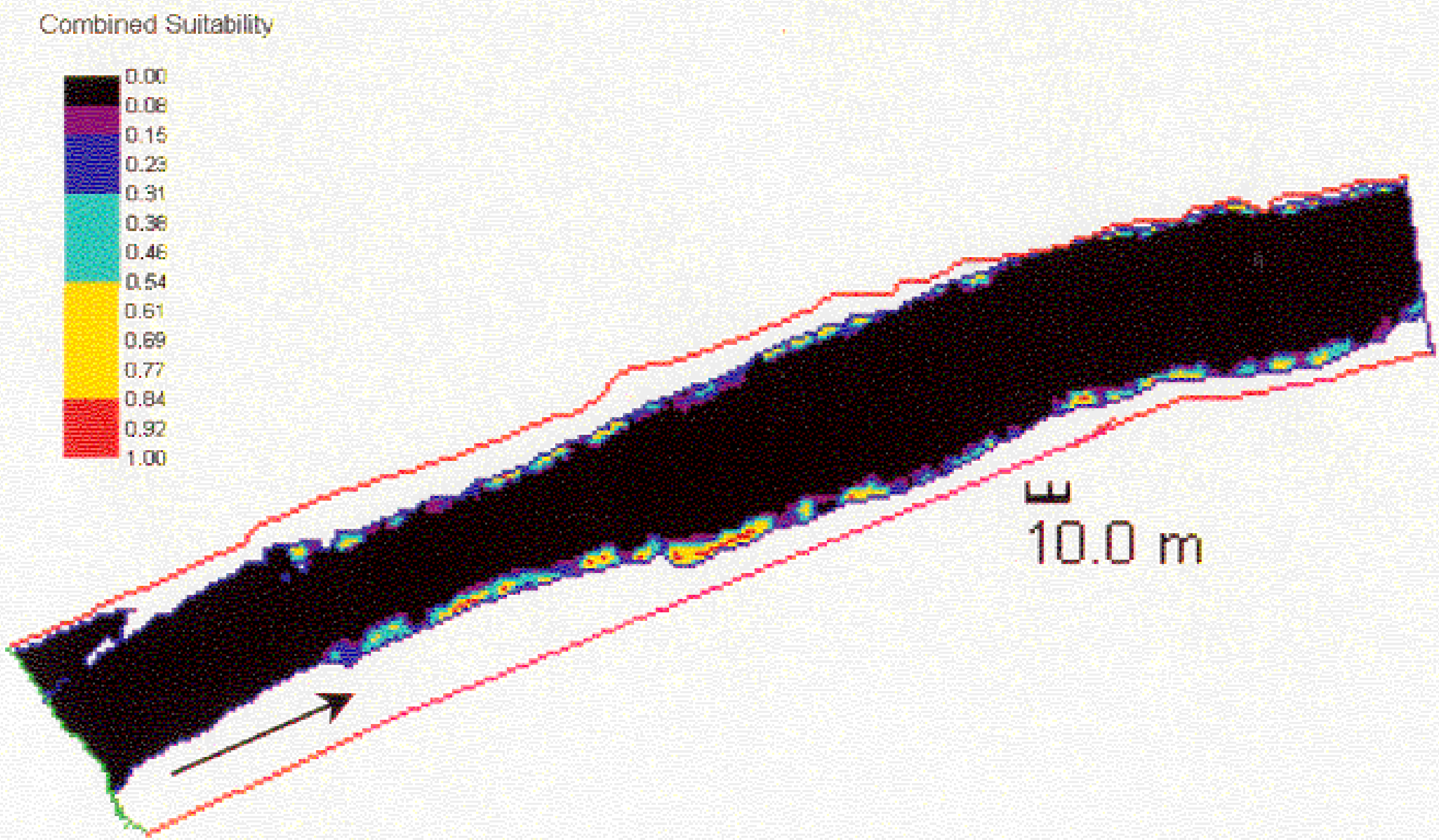


Fig. A 2. Chinook salmon fry compound suitability at the rehabilitation site. Arrow shows flow direction, flow is 35.4 m^3/s.

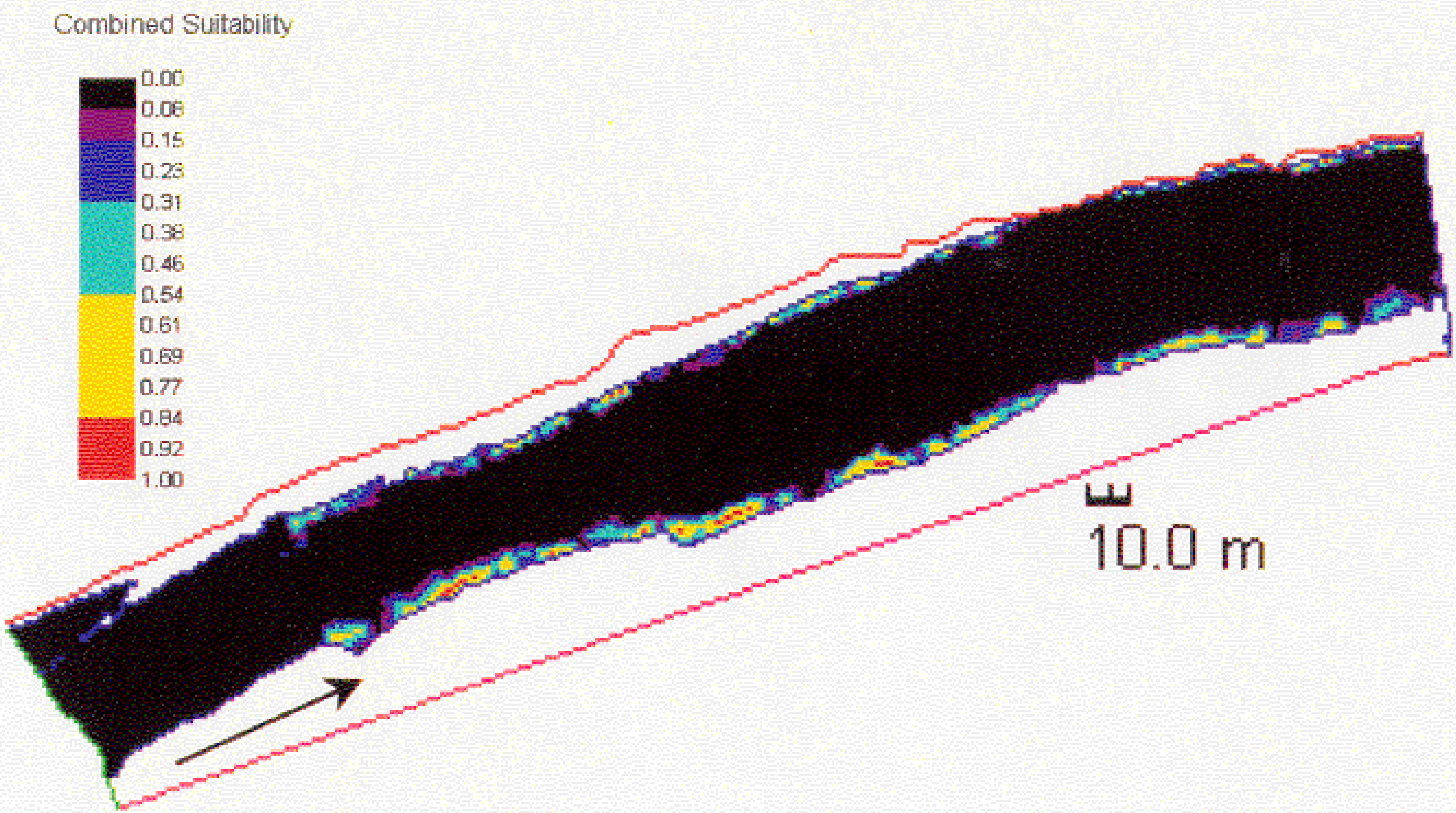


Fig. A 3. Chinook salmon fry compound suitability at the rehabilitation site. Arrow shows flow direction, flow is 45.0 m^3/s.

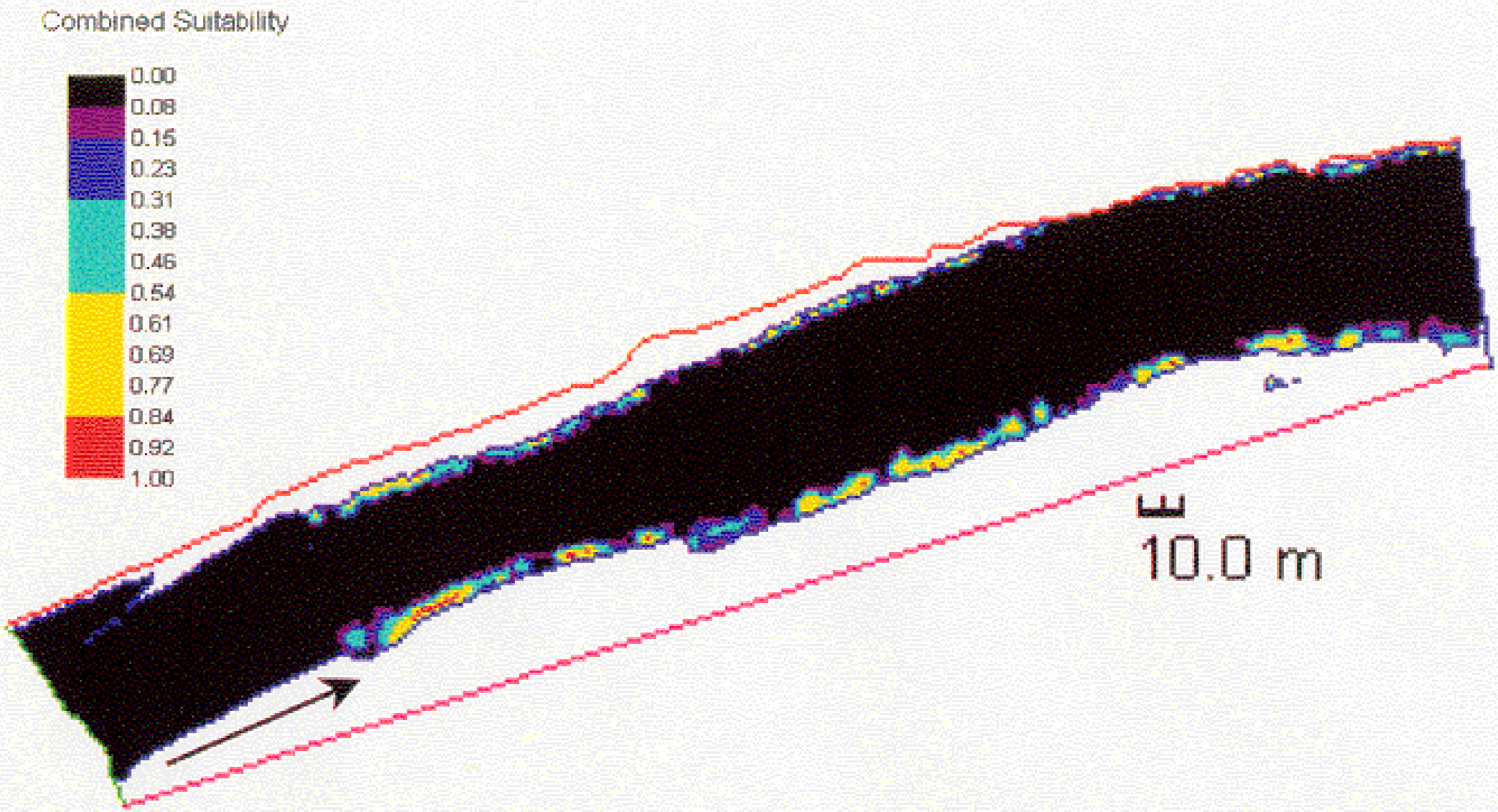


Fig. A 4. Chinook salmon fry compound suitability at the rehabilitation site. Arrow indicates flow direction, flow is 61.4 m^3/s.

APPENDIX B

Chinook Salmon Fry Compound Suitability for
the Control Site

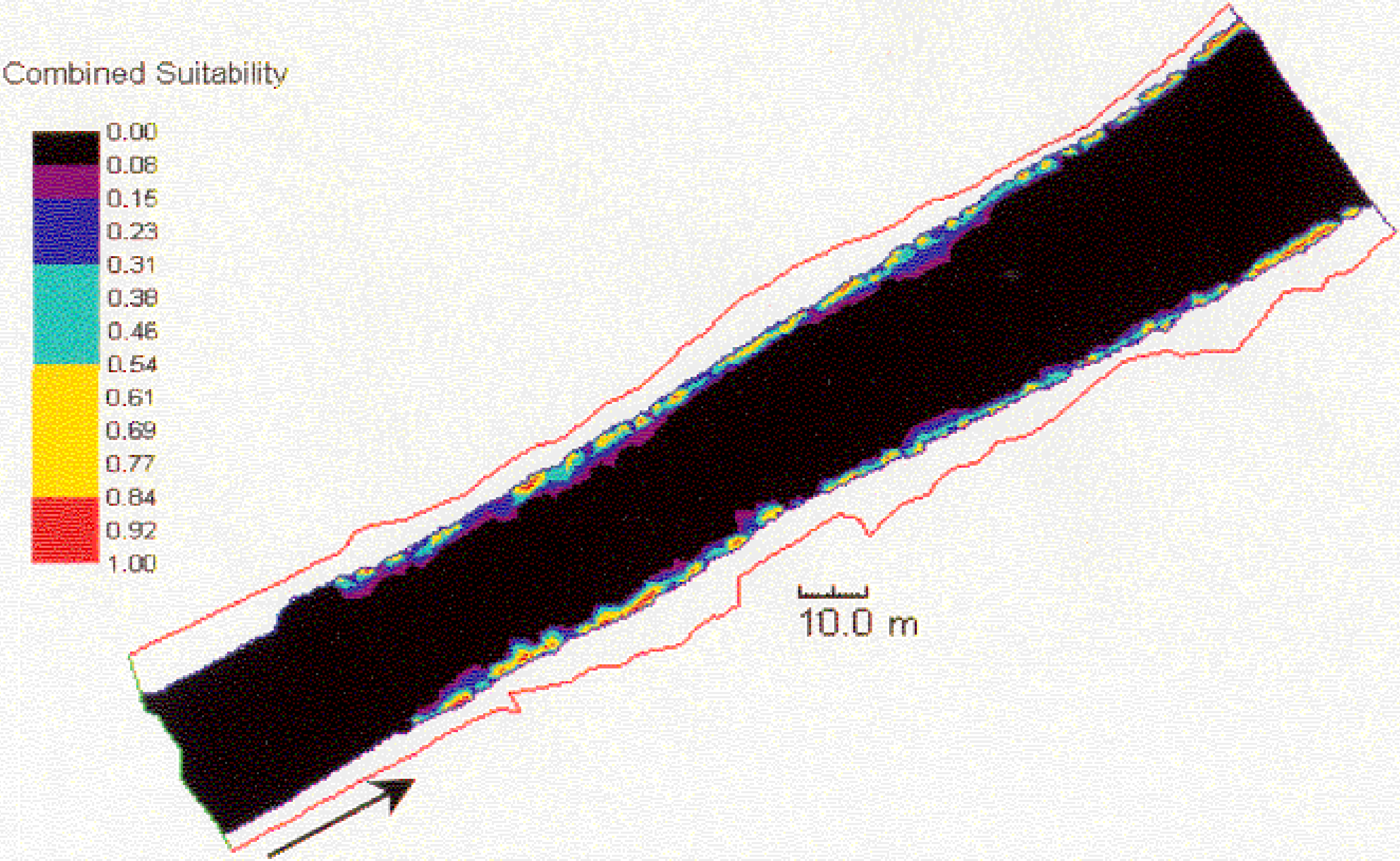


Fig. B 1. Chinook salmon fry compound suitability at the control site. Arrow shows flow direction, flow is 15.8 m^3/s.

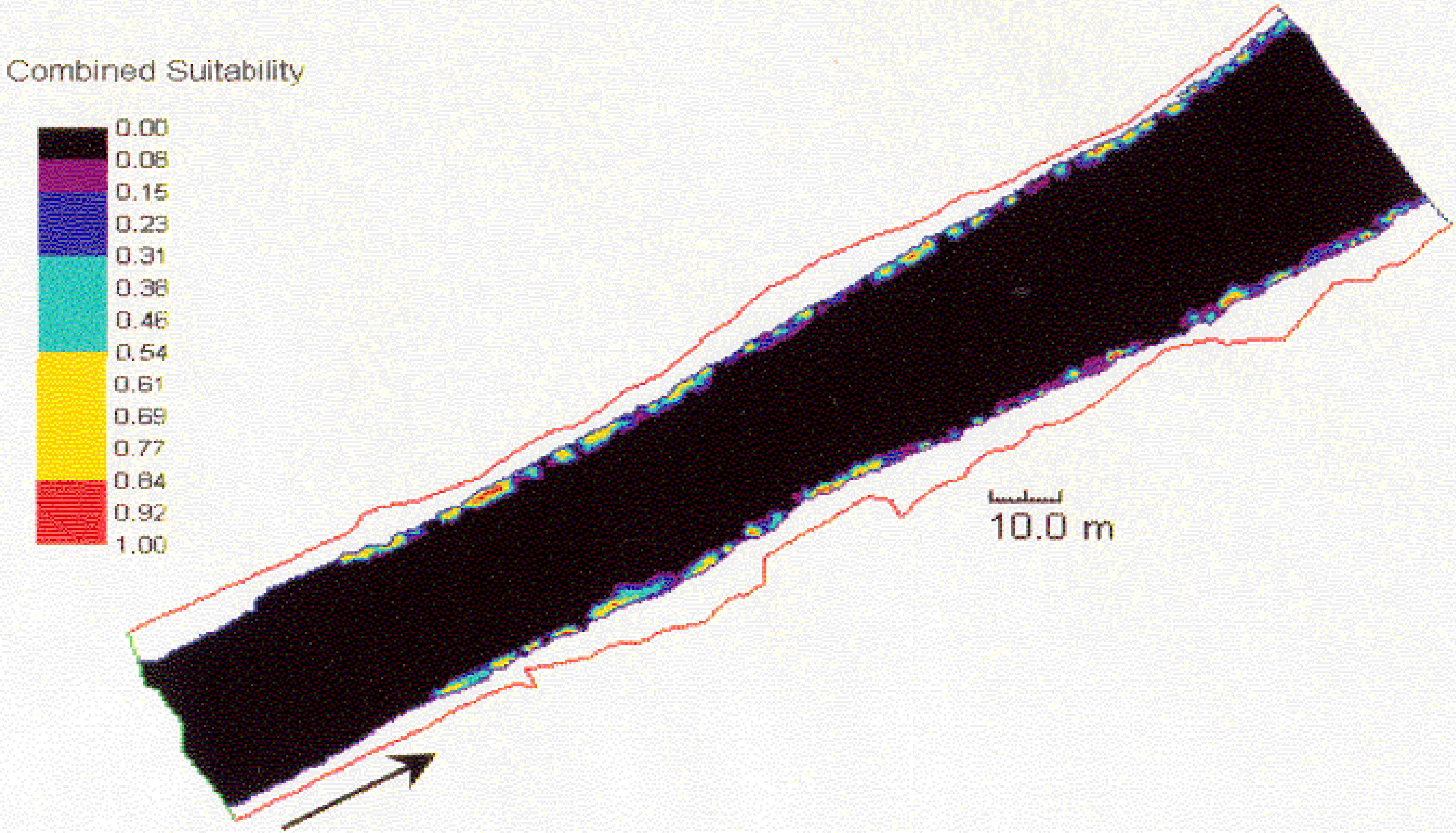


Fig. B 2. Chinook salmon fry compound suitability at the control site. Arrow shows flow direction, flow is 35.4 m^3/s.

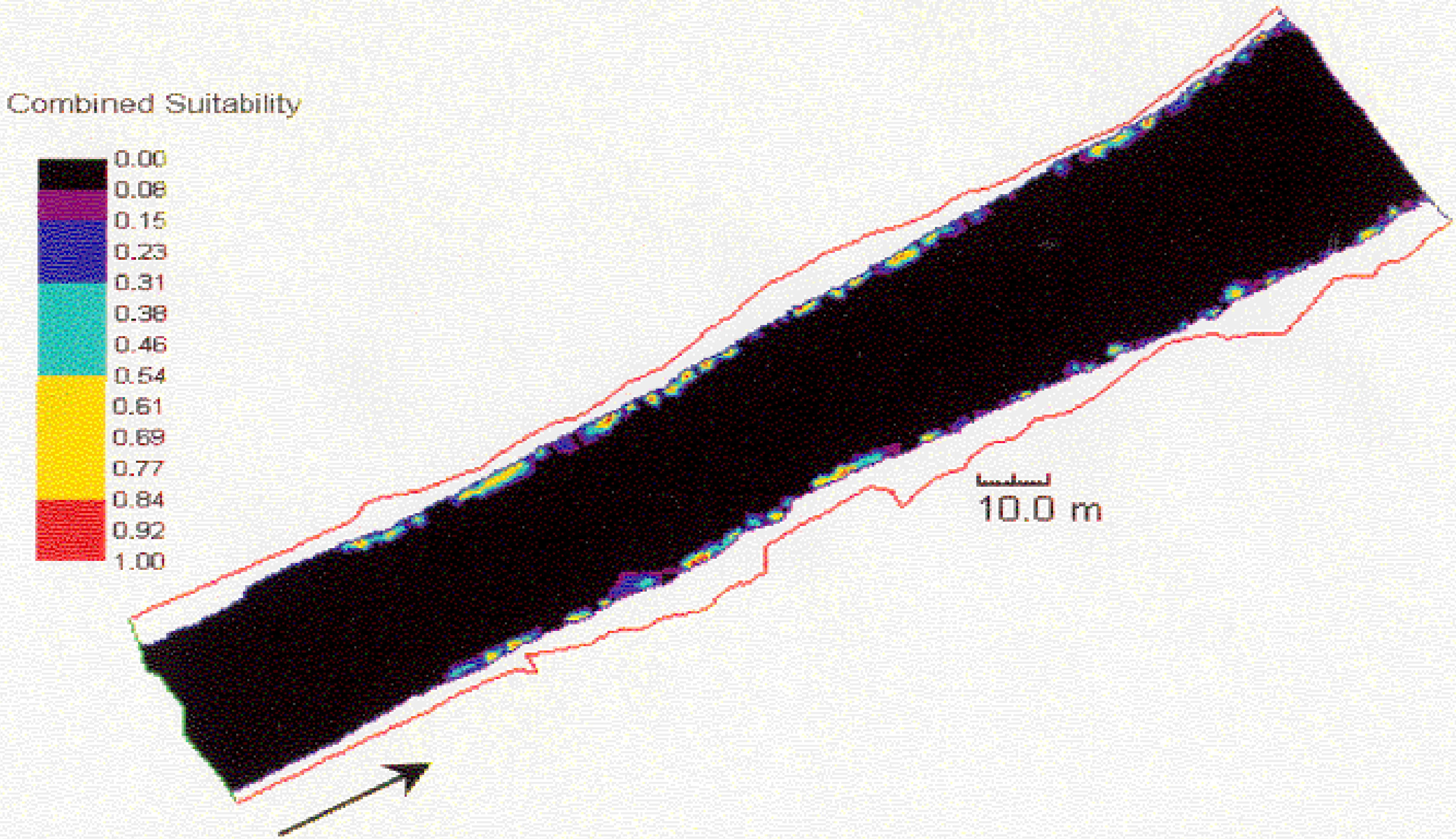


Fig. B 3. Chinook salmon fry compound suitability at the control site. Arrow shows flow direction, flow is 45.0 m^3/s.

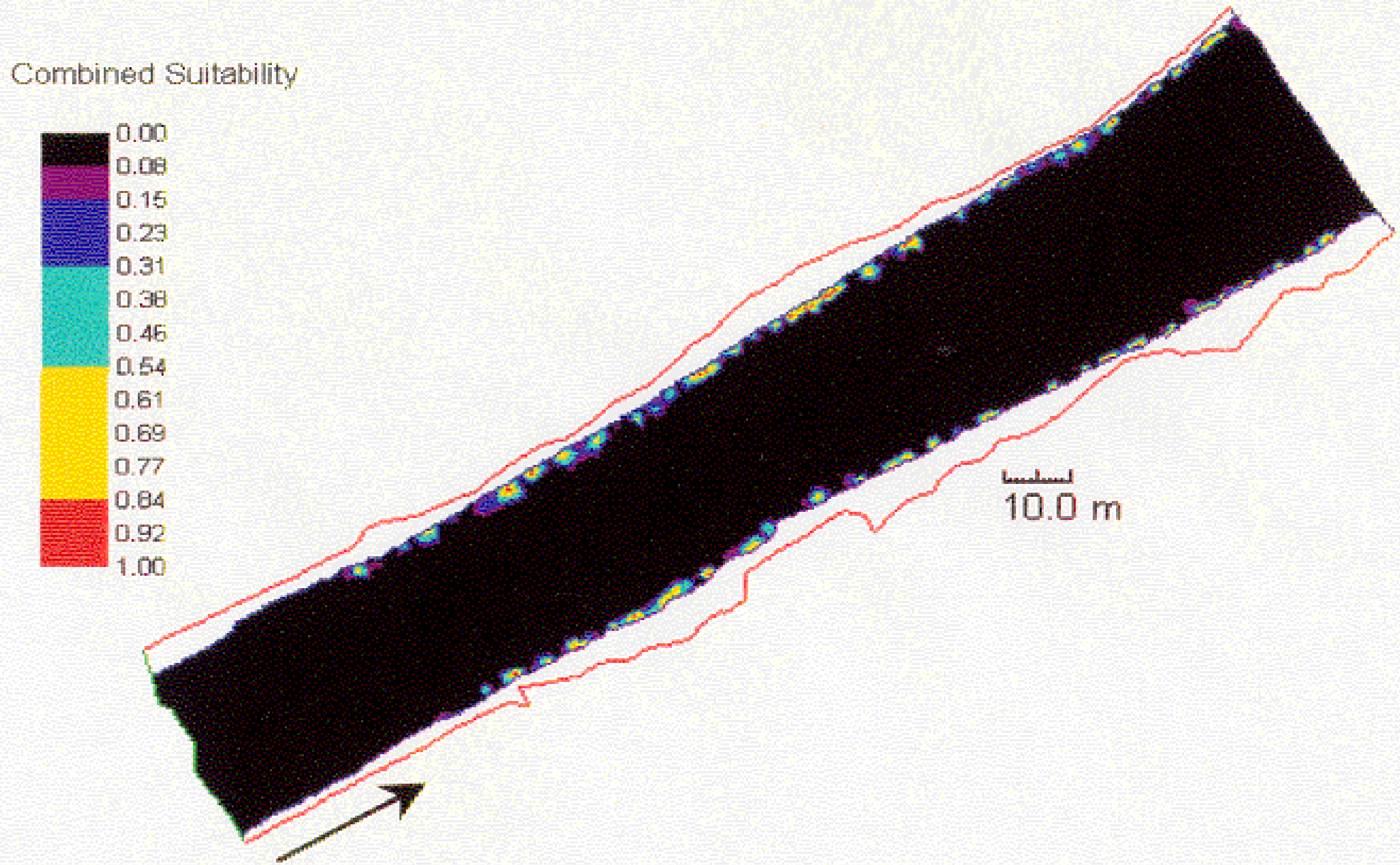


Fig. B 4. Chinook salmon fry compound suitability at the control site. Arrow shows flow direction, flow is 61.4 m^3/s.

APPENDIX C

Chinook Salmon Fry Compound Suitability for
the Hypothetical Rehabilitation Site

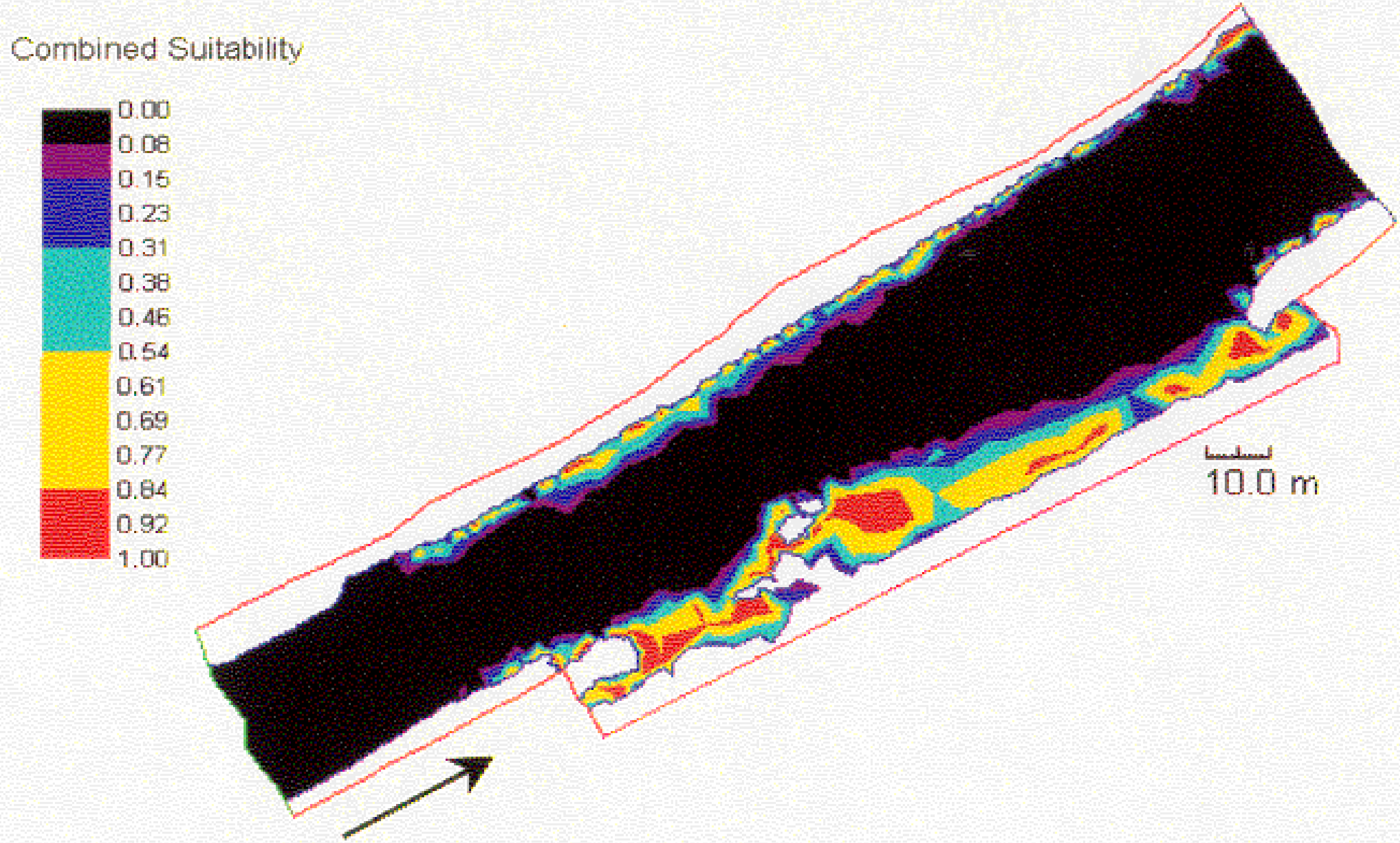


Fig. C 1. Chinook salmon fry compound suitability for a hypothetical rehabilitation of the control site. Arrow ishows flow direction, flow is 15.8 m^3/s.

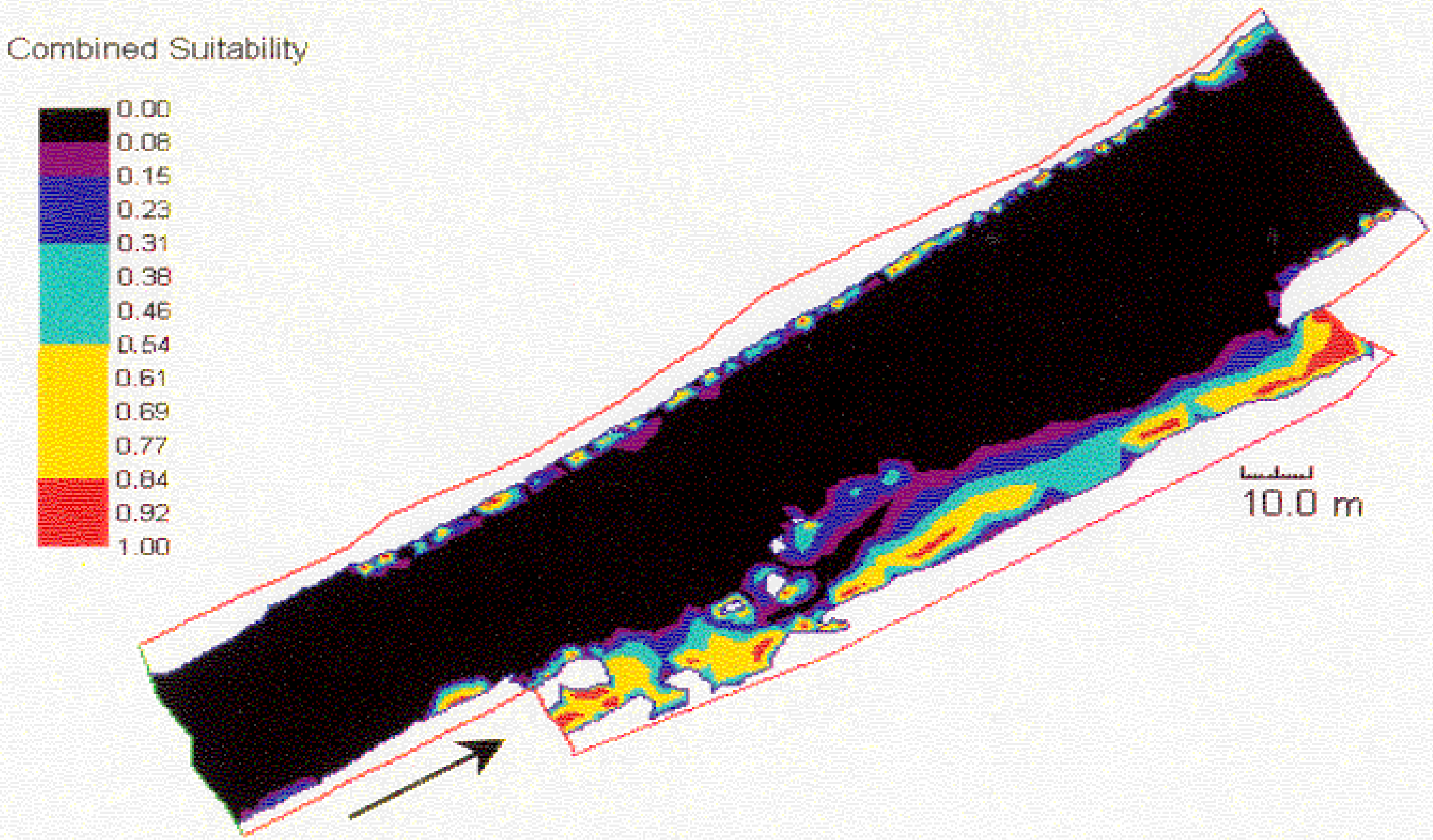


Fig. C 2. Chinook salmon fry compound suitability for a hypothetical rehabilitation of the control site. Arrow shows flow direction, flow is 45.0 m^3/s.

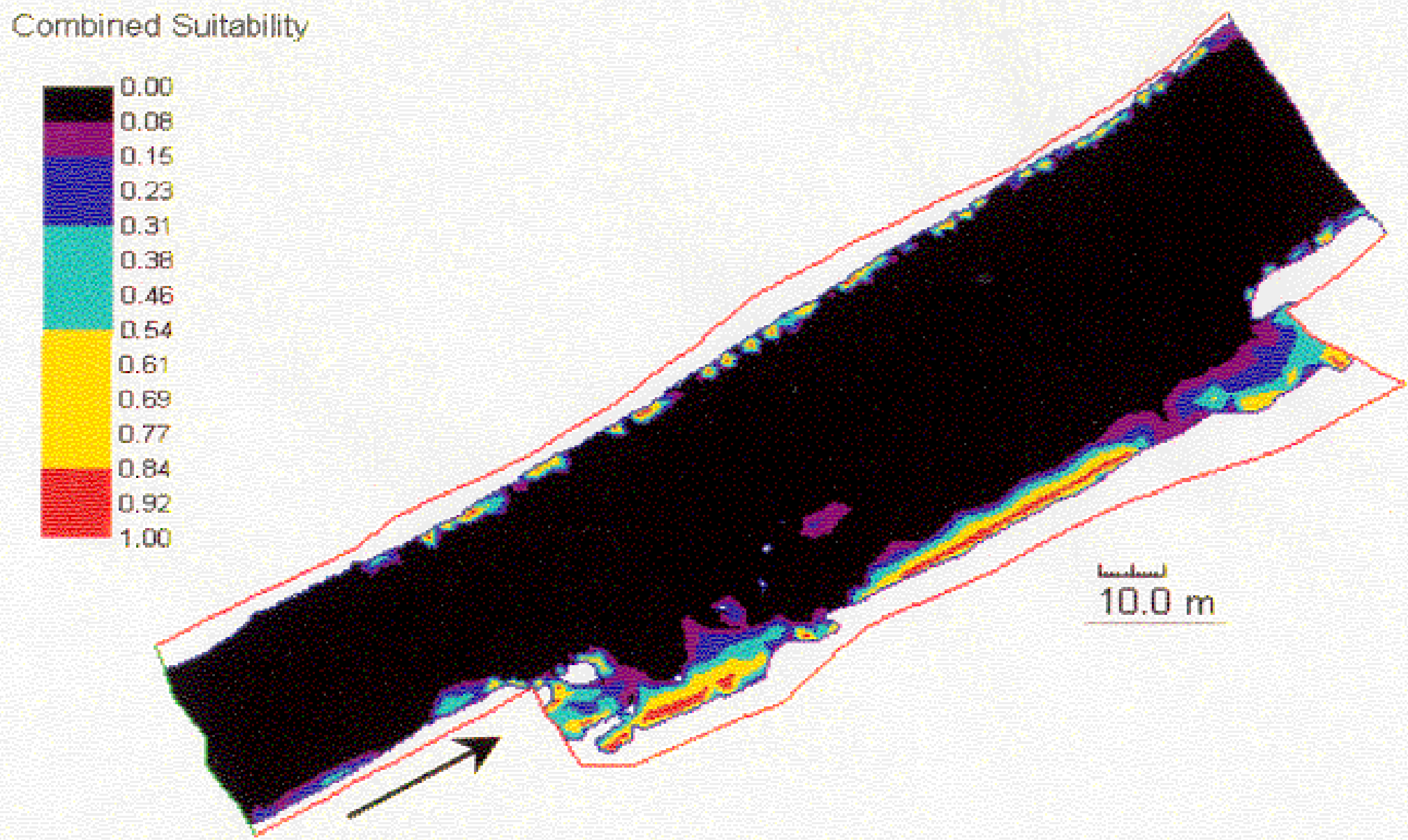


Fig. C 3. Chinook salmon fry compound suitability for a hypothetical rehabilitation of the control site. Arrow shows flow direction, flow is 61.4 m^3/s.