Proposal to Study Dissolved-Oxygen Requirements of South Platte River Fishes and Implications For a Site-Specific Standard

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STATEMENT OF PROBLEM

The South Platte River, like many large rivers in the U.S., is a "working river". As it flows through eastern Colorado, the South Platte River serves as a source of water for municipalities, agriculture, industry, and is used as a receiving water. The United States Environmental Protection Agency (USEPA) has been mandated by Congress to establish water-quality criteria that protect aquatic life in receiving waters. In response to this mandate, the USEPA has developed national criteria for a variety of pollutants that may occur in any body of water. Unfortunately, because national criteria must be protective over a broad range of environmental conditions, they may be overly conservative at some specific locales.

The Metro Wastewater Reclamation District (MWRD) operates a large sewage treatment plant located in Denver, Colorado, and is a major discharger to the South Platte River. Recent improvements in the facility have brought it closer to complete compliance with all USEPA guidelines; however, portions of the South Platte River downstream of the MWRD discharge show extreme seasonal fluctuations in dissolved-oxygen concentrations. In some reaches of the river, dissolved-oxygen concentrations are reported (R. Erickson, USEPA, personal communication) to be below USEPA national criteria minima for protection of warmwater fish (Chapman 1986).

The existing national criteria for ambient dissolved-oxygen concentrations for protection of warmwater fishes (hereafter referred to as "national criteria") specify that for early life stages (ELS) a 7-day mean and 1-day instantaneous minimum of 6.0 and 5.0 mg/L dissolved oxygen must be maintained. For other life

stages (OLS) a 30-day mean, 7-day mean minimum, and 1-day instantaneous minimum of 5.5, 4.0, and 3.0 mg/L, respectively, are required. Additionally, the State of Colorado has its own dissolved-oxygen standards that are identical to the national criteria for ELS but are slightly less conservative for OLS: 30-day mean of 5.5 mg/L, a 7-day mean minimum of 5.0 mg/L from May 1 to July 31 and 4.5 mg/L for the remainder of the year, and a 1-day instantaneous minimum of 3.0 mg/L.

STATEMENT OF NEED

The recurrent low dissolved-oxygen conditions in the South Platte River are probably due, at least partly, to nutrients added by the MWRD. Metro Wastewater Reclamation District is responding to this problem by determining what measures can be taken to eliminate or reduce low dissolved-oxygen conditions. In conjunction with an assessment of remediation alternatives, MWRD is recommending that the appropriateness of the national criteria be evaluated for the portion of the South Platte River potentially effected. If the national criteria are found to be overly conservative for this portion of the South Platte River, then MWRD may recommend the establishment of a site-specific dissolved-oxygen standard that is fully protective of aquatic life. The site-specific standard would be implemented in a portion of the South Platte River known as segment 15 (R. Erickson, USEPA, personal communication). This reach of river begins just upstream of the MWRD outfall and extends downstream to Fort Lupton, Colorado.

PROPOSED STUDY

To develop a sufficient database to determine if there is justification for a site-specific standard for segment 15, we propose a 2-year study of the environmental and biological conditions in segment 15, and a series of laboratory tests. Information gathered from these investigations will be used to estimate dissolved-oxygen concentrations that will protect all life stages of resident, and potentially resident, warmwater fishes using the same guidelines for impairment set forth by USEPA in the national criteria (Chapman 1986, page 30).

In designing physical, chemical, and biological sampling schemes, consideration was given to methods that can be used before and after remediation and be sensitive to changes that may occur. Provided that the proposed research is implemented at least 1 year before any remediation takes place, data collected

will fit into an experimental design known as the optimal impact study design (Green 1979). The scheme utilizes sampling before and after a manipulation (remediation) at reference and impacted monitoring sites. By using this design, a strong inference can be made as to effects of the manipulation, and powerful statistical methods are available for data analysis. Because one of the objectives of any program to develop a site-specific standard must include field evaluation of the new standard, it is important that experimental design and statistical considerations be made in initial phases of the study.

A description of objectives and tasks, by year, are given below. The relationship of each objective to other objectives, and to the goal of determining if a site-specific standard is justified for segment 15, is illustrated in a flow chart (Figure 1). However, it should be noted that as more is learned about environmental conditions and fishes in segment 15, some objectives may be modified (as agreed upon by MWRD, USEPA, and LFL) in order to take advantage of new information.

OBJECTIVES FOR YEAR 1, March 1992 - February 1993

OBJECTIVE 1

Complete a comprehensive review of dissolved-oxygen literature relevant to South Platte River field and laboratory studies.

Purpose

Larval Fish Laboratory personnel have completed an intensive survey and summary of literature related to dissolved oxygen published since 1985 (Snyder 1991), but a review of literature published prior to 1985 is incomplete. A comprehensive review will allow us to evaluate existing data and national criteria within the context in which they were developed. Circumstances (e.g., effects on fishes not studied previously, effects at selected water temperatures, and effects under fluctuating dissolved oxygen conditions) where national criteria may be overly conservative will be identified.

Methods

A majority of the literature search will be conducted using electronic bibliographic databases. Other sources of pertinent information will include USEPA libraries, reviews of literature related to dissolved oxygen, and references given in papers previously reviewed for this project.

End Product

Pertinent literature will be obtained and maintained in the Larval Fish Laboratory library. References will be indexed using a computer bibliographic database called Reference Manager (Research Information Systems Incorporated, Carlsbad, California).

OBJECTIVE 2

Establish one reference monitoring site (preferably upstream of MWRD outfall) and three impacted monitoring sites within segment 15.

Purpose

The careful selection and establishment of permanent monitoring sites is crucial to the success of this study. Selection of monitoring sites that are physically similar will reduce effects of confounding environmental factors. Monitoring sites will be representative of the type and abundance of habitats that occur within segment 15. Standardizing monitoring sites in this manner will allow us to determine: 1) which fishes consistently occur in specific habitats; and 2) the dissolved oxygen and temperature profiles in specific habitats at each monitoring site.

Methods

Reference and impacted monitoring sites will contain a variety of habitats (e.g., pool, riffle, run, and backwater) as defined by an accepted classification scheme (Haynes and Muth 1984; see Appendix A). Preliminary criteria for selection of monitoring sites are that each site contain a large pool impounded by a roller dam, and one or more riffle, pool, run, and backwater habitats. The latter four habitats will be located upstream of the large pool so that they will not be affected by it. These habitats will be identified qualitatively so that a record of fishes captured in each habitat can be maintained (see objective 4). Habitats will not be quantified (i.e., the amount of each habitat type in a section of the South Platte River will not be determined). If MWRD, USEPA, Colorado Division of Wildlife, or U.S. Geological Survey have existing study sites that meet our selection criteria, then consideration will be given to use of those locations.

A major concern is that water diversions and returns may confound attempts to select similar monitoring sites, especially with regard to the upstream reference site. Ideally the reference monitoring sites will be located in the South Platte River, upstream of the MWRD outfall.

However, if an acceptable reference monitoring site cannot be established upstream of segment 15, consideration will be given to establishing it: 1) downstream, in a relatively unimpacted (recovered) portion of the South Platte River; or 2) in a tributary to the South Platte River. However, establishing the reference monitoring site in the South Platte River is preferred so that it can be used as a control for factors that may affect the biological community (e.g., floods, drought, and chemical spills). United States Geological Survey discharge records (Ugland et al. 1991) taken from a gauge near the 19th Street bridge in Denver (upstream of the MWRD) show that although discharge is typically less at this locale than in segment 15 (as represented by discharge records taken from a gauge on State Highway 22, 0.2 miles northwest of Henderson, Colorado), it is usually of the same magnitude and often within 2.8 m^3/s (100 $feet^3/s$).

In addition to habitat similarity, locations of the three impacted monitoring sites will be dependent on existing information and accessibility. Preliminary data (R. Erickson, USEPA, personal communication) show that there are three reaches within segment 15 that have distinctive dissolved-oxygen patterns (Figure 2). We propose to establish one site in an apparently strongly impacted reach between 88th and 104th Avenue, a second site in a less impacted reach 16-24 km downstream of MWRD, and a third site 32-39 km downstream of MWRD, just upstream of Fort Lupton. These monitoring sites are approximately evenly spaced throughout segment 15 and will allow us to determine if there are important physical, chemical, or biological trends related to distance from the MWRD outfall.

End Product

Descriptions of monitoring site locations and available habitat will be recorded (using video, photographs, and maps) to ensure that monitoring sites can be consistently used in future work. Collections at monitoring sites will provide baseline information that can be used to evaluate effectiveness of remediation (e.g., 88th Street reconstruction).

OBJECTIVE 3

Describe the extent and periodicity (seasonal and diel) of dissolved oxygen and temperature fluctuations at reference and impacted monitoring sites. Identify other contaminants that may confound effects of dissolved oxygen.

Purpose

To determine if there is justification for a site-specific standard for dissolved oxygen in segment 15, a thorough description of the current physical and chemical conditions is required. Effects of low dissolved oxygen are exacerbated at higher temperatures, therefore, temperature conditions within segment 15 must also be described. Physical and chemical data will be used to determine if there are other environmental factors or contaminants that may be responsible for existing biological conditions. Physical and chemical information will also be used in designing laboratory studies (see objective 7); data supplied to the LFL to date are inadequate for this purpose.

Methods

Dissolved oxygen and temperature will be monitored continuously at selected monitoring sites using self-contained remote monitoring instruments (DataSonde 3 water quality datalogger, Hydrolab Corporation, Austin, Texas). Three monitoring instruments will be purchased. One instrument will be deployed in the main channel at the reference monitoring site and will be used as a reference. The other two instruments will be deployed together at selected locations. For example, at impacted monitoring sites, one instrument will measure conditions in the main channel, the other will simultaneously measure conditions in another habitat (e.g., pool or backwater). These data will allow description of dissolved-oxygen and temperature relationships between main channel and other habitats. Descriptions of environmental conditions in habitats other than the main channel are needed because young fish typically occupy low-velocity habitats like pools and backwaters.

In addition to remote monitoring instruments, measurements of dissolved oxygen and temperature will be made in conjunction with biological collections (samples collected every 4-6 weeks at each monitoring site, see objective 4). These measurements will be made using a YSI model 57 dissolved-oxygen meter (YSI Incorporated, Yellow Springs, Ohio). Habitat-related dissolved-oxygen measurements will be used to determine if certain habitats are predisposed to low dissolved-oxygen conditions and if these conditions are of relative importance to the fish fauna.

To identify other factors which may be responsible for observed biological trends, water-quality analyses will be conducted on water samples collected in conjunction with

biological collections. Of principle interest will be field analyses for contaminants that may be related to the factors responsible for dissolved-oxygen fluctuations (i.e., CO_2, NH_3, H_2S, and Cl_2). These contaminants are of special interest for the following reasons: 1) laboratory studies have shown fishes may avoid waters with high concentrations of CO_2; 2) un-ionized ammonia originating from MWRD, or produced by biological processes within the South Platte River, may affect distribution and abundance of fishes; 3) H_2S is a toxic compound that may be produced by biological processes within the South Platte River and may affect distribution and abundance of fishes; and 4) residual chlorine that may originate from MWRD is highly toxic to fish. Other water-quality characteristics that will be measured are: alkalinity, conductivity, hardness, and pH. These analyses and calibration of dissolved-oxygen instruments will be conducted using a Hach model DREL/2000 portable laboratory (Hach Company, Loveland, Colorado). Water samples will also be scanned for other potential contaminants (Soils Laboratory, CSU, see Appendix B for list of contaminants and detection limits).

End Product

A detailed description of physical and chemical conditions at each monitoring site will be produced. Simultaneous measurements of dissolved oxygen and temperature by remote monitoring instruments at reference and impacted monitoring sites will reduce the likelihood that data will be confounded by effects of weather and discharge. Data describing timing and extent of dissolved-oxygen concentrations in segment 15 will be summarized. Data will be used when designing laboratory studies. Other contaminants that may contribute to (confound dissolved oxygen effects) the observed biological condition of segment 15 will be identified and measured.

OBJECTIVE 4

Determine spatial (habitat use) and temporal (seasonal) distribution of species and life stages of fishes in segment 15 and the reference reach. Compile a species list of fishes that currently inhabit segment 15 and the reference monitoring sites.

Purpose

The primary purpose of this objective is to determine what species are present in segment 15. Information on spatial and temporal distribution will be used to identify

which habitats are utilized by early and other life stages and at what time of year habitat utilization occurs. Spatial and temporal information will be compared with dissolved-oxygen data to determine which species and life stages are likely to be affected by low dissolved-oxygen conditions. Resulting information will also be used to evaluate the utility and completeness of fish surveys conducted by the Colorado Division of Wildlife and MWRD.

Methods

A thorough faunal survey of fishes at the four monitoring sites will be made on 6-8 occasions between 1 March and 31 October 1992 at 4-6 week intervals. Methods and gear types used to capture fish will include: electro-fishing, seines, gill/trammel nets, dipnets, and light traps. Fish will be collected from specific habitats at each monitoring site using consistent gear types and effort. Captured fish will be identified to species, counted, weighed, measured, and released alive when work at that monitoring site is concluded. Scale samples will be taken from a subsample of the fish captured to verify age-length relationships. Some fish will be retained for use in "autopsy-based condition assessment" (see objective 5).

In addition to monitoring site collections, a qualitative fish survey of the South Platte River from MWRD to Fort Lupton, including the ~~referenee~~ monitoring site, will be conducted on one occasion just prior to the onset of low dissolved-oxygen conditions. Sampling will be concentrated in shoreline habitats and will utilize seines, and dipnets. Emphasis of this survey will be to make collections in habitats that do not occur at the monitoring sites (e.g., confluences, springs, and irrigation returns). Such habitats may be occupied by fishes that would not be collected at monitoring sites. Historical collections have shown that many more species may occur in segment 15 than are usually collected (Snyder 1991).

End Product

This sampling design will produce a relatively complete list of resident species and allow estimation of relative abundance, age-size structure, and habitat use. It will also detect reproduction and reveal if all life stages continuously reside at each monitoring site (and in segment 15) or if they occupy monitoring sites on a seasonal basis.

OBJECTIVE 5

Use "autopsy-based condition assessment" (ABCA) to evaluate health and physiological status of individual fish and selected fish populations at all monitoring sites.

Purpose

The ABCA (Goede 1990) is a procedure that qualitatively and quantitatively assesses disease, condition, and physical manifestations of physiological stress. It is designed for use in the field and does not require expensive equipment or complicated biochemical analysis. The ABCA measures characteristics that are affected by long-term exposure to adverse environmental conditions. It is a useful tool with which to gauge the health and condition of a population of fish.

Methods

The ABCA will be conducted at all four monitoring sites on two occasions each year. The first sample set will be taken just prior to onset of sub-national criteria dissolved-oxygen conditions (probably in July) and the second sample set will be taken after low dissolved-oxygen conditions have been present for several weeks (late October). By statistically comparing the ABCA of fish taken from reference and impacted monitoring sites, before and after the onset of low dissolved-oxygen conditions, it will be possible to determine if incidence of disease and condition are significantly different ($p \leq 0.05$) at reference and impacted monitoring sites.

End Product

The ABCA will provide an objective measure of the health and condition of fish and fish populations in reference and impacted monitoring sites. The ABCA has been shown to be an effective tool with which to measure stress in fish populations and is especially appropriate for stress induced by low dissolved oxygen (R. Goede, Utah Department of Natural Resources, personal communication). It is currently being used by USEPA to monitor redbreast sunfish (Lepomis auritus) populations, and by the Tennessee Valley Authority to monitor largemouth bass (Micropterus salmoides) and channel catfish (Ictalurus punctatus) populations. The method will be used to determine if existing conditions are detrimental to fish and fish populations in segment 15. It will also be useful in evaluating remediation. A comparison of ABCA scores obtained before and after remediation will

show if the health and condition of fish in segment 15 have improved.

OBJECTIVE 6

Conduct an index of biotic integrity (IBI) analysis on the stream-fish community at all monitoring sites and use index scores to compare the quality of the water resources.

Purpose

The IBI as proposed by Karr (1981) is a tool for analysis and interpretation of faunal-survey data collected from stream-fish communities. The index incorporates a variety of community attributes and integrates them into a single value called an IBI score. We will use a version of the IBI that was specifically developed for the South Platte River Basin (Schrader 1989) to assess the quality of aquatic resources at each monitoring site.

Methods

An IBI score will be calculated for each monitoring site after each sampling occasion. Data will be subjected to tests of normality and homogeneity-of-variance before statistical analysis. Comparisons to determine if IBI scores at certain monitoring sites or times of year are significantly different ($p \leq 0.05$) from others will be made using analysis-of-variance and regression. Statistical tests will include: 1) comparisons to determine if mean IBI scores at each monitoring site are different from those at other monitoring sites; and 2) analyses to determine if there is a consistent trend of IBI scores with increasing distance from the MWRD outfall.

End Product

The IBI will provide an objective method with which to integrate attributes of stream-fish community structure at each monitoring site. Statistical comparisons will determine if impacted monitoring sites are significantly different from the reference monitoring site and if some sites are more adversely affected than others. This analysis will also provide baseline data for evaluation of remediation.

OBJECTIVE 7

Conduct laboratory studies to empirically determine acceptable dissolved-oxygen concentrations for a site-specific standard in segment 15.

Purpose

The national criteria for dissolved oxygen is based on results of a variety of experiments in which there was little standardization of methods. Because of its nation-wide applicability, the national criteria may be under- or overly protective of fishes in segment 15. A determination of whether or not a site-specific standard is appropriate in segment 15 should include evidence from field and laboratory studies.

We propose laboratory experiments where ELS of selected fishes will be exposed to a series of dissolved-oxygen concentrations. Experimental concentrations will be modelled after diel patterns of dissolved oxygen observed at impacted monitoring sites. The experiments will provide a quantitative assessment of the amount of production impairment (i.e., growth reduction) that is likely to result as a function of dissolved-oxygen concentration. National criteria may be overly protective because they are based on experiments where dissolved-oxygen concentrations were held constant during the exposure period. We propose to use an exposure system that will produce fluctuating dissolved-oxygen concentrations. Test fish will be exposed to low oxygen conditions for only a portion of each 24-hour period. Estimates of production impairment at respective dissolved-oxygen regimes will probably be less than those predicted by the national criteria. These less conservative estimates of dissolved-oxygen requirements will result from using a more environmentally realistic series of exposure concentrations (i.e., fluctuating) than those on which the national criteria are based. If warranted, this information can be used to estimate a site-specific standard for dissolved oxygen. Such a standard would be consistent with the guidelines used to establish the national criteria and account for environmental conditions in segment 15.

Methods

Laboratory exposures will be conducted following protocols for toxicity testing recommended by the American Society for Testing and Materials (1990) and Weber et al. (1989). A laboratory exposure system will be constructed that will continuously produce five fluctuating dissolved-oxygen concentrations (treatments). Each treatment will be

randomly assigned to four replicate aquaria containing 30 test organisms. Dissolved-oxygen treatments will be formulated by de-oxygenating well water via N_2 stripping and then re-oxygenating to target concentrations. Well water will be re-oxygenated by pumping air through it. By systematically stopping or starting air pumps, dissolved-oxygen concentrations can be made to decrease or increase, respectively. Dissolved oxygen concentrations in each treatment will be verified by measuring them at hourly intervals for 24 hours on two occasions per week.

Three species of fish will be tested: fathead minnow (Pimephales promelas); channel catfish; and largemouth bass. These species are available from commercial sources and have been used in studies incorporated into the national criteria. In addition, fathead minnow and channel catfish are native to the South Platte River, and all three species have been collected in or near segment 15 (Snyder 1991).

During the test exposures, water temperature will be 22 $\pm$ 2 °C as recommended by ASTM (1990). At the start of the exposure period, test organisms will be newly fertilized eggs (less than 24 hours old). The exposure period will continue until larvae begin feeding exogenously or die. This exposure period typically includes the most sensitive life stages and will last from 7 to 21 days depending on which species is being tested and the dissolved-oxygen treatment. Biological effects of the treatments will be determined by measuring a variety of commonly used endpoints (e.g., % eggs hatching, % larvae surviving to first feeding, weight at first feeding, time to hatching, time to first feeding, etc.). Time to first feeding will be determined by presenting test animals with 24-hour-old brine shrimp on a daily basis and counting the number of fish with food in their gut after 1 hour. Data will be subjected to tests of normality and homogeneity-of-variance before being analyzed by analysis-of-variance and/or regression. Treatment effects on survival at the 0.05 level of statistical significance will be considered biologically detrimental. Dissolved-oxygen treatments that reduce growth by 10% or more (this value equivalent to slight production impairment used by Chapman (1986) to establish national criteria), compared to control animals will be considered biologically significant.

Empirical data on which to describe a dissolved-oxygen profile that would mimic conditions in the South Platte River have not been made available to the LFL. Therefore, we preliminarily propose an exposure system that will produce an approximately sinusoidal pattern of dissolved-

oxygen concentrations. Experimental treatments will have daily dissolved-oxygen lows, highs, and durations as described in Table 1. These test conditions may be modified as environmental conditions in segment 15 are described in greater detail. The exposure apparatus will be constructed and tested during summer and fall 1992. Tests with fathead minnow will be conducted during winter 1992-1993. Tests with channel catfish and largemouth bass will be conducted during spring and summer 1993.

End Product

Results of laboratory studies will provide a new data set with which to judge the appropriateness of the national criteria. The new data will be based on an environmentally realistic series of fluctuating dissolved-oxygen concentrations. Because test animals will be exposed to dissolved-oxygen concentrations below the national criteria for only a portion of every 24-hour period, the effects of exposure will probably be much less than those predicted by the national criteria.

STUDY SCHEDULE YEAR 1, March 1992 - February 1993

Obj[a]	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
1	X											
2	X											
3	X	X	X	X	X	X	X	X	X			
4	X	X	X	X	X	X	X	X				
5					X	X	X					
6	X	X	X	X	X	X	X	X				
7					X	X	X	X	X	X		

[a]1=literature review, 2=monitoring site selection, 3=water quality monitoring, 4=fish survey, 5=autopsy-based condition assessment analysis, 6=index of biotic integrity analysis, 7=laboratory studies.

Deliverables

Written status reports submitted on a quarterly basis. Annual reports submitted at conclusion of each fiscal year.

BUDGET YEAR 1, March 1992 - February 1993

	Dollars
Salaries and benefits	
Administrator (1 month)	3,084
Research associate (12 months)	30,000
Research associate (8 months)	20,000
Technicians (four 6-month positions)	26,880
Benefits for eligible personnel (20000 X 19.3%)	3,860
Subtotal	83,824
Equipment	
Three DataSonde 3 water quality dataloggers	13,800
DREL 2000 portable laboratory	2,700
9.9 horsepower outboard motor	1,800
Model 57 dissolved oxygen meter	965
Chart recorder	1,035
Centrifuge	950
Subtotal	21,250
Supplies	
Field	2,874
Laboratory	4,400
Subtotal	7,274
Travel and per diem	3,600
Services (water analysis, 24 samples)	1,600
Publication costs	1,000
Total direct costs	118,548
Indirect costs (15% CSU overhead)	17,783
Total project cost	136,331

*Note: 15% overhead rate applies to "fixed price" projects. If payment is not on a "fixed price" basis, a 45% overhead rate may apply.

OBJECTIVES FOR YEAR 2, March 1993 - February 1994

The principle focus of work during year 2 will be to replicate field measurements. Replicate data will provide an estimate of the year-to-year variation at each monitoring site and prevent conditions resulting from some random event (e.g., floods or chemical spills) from being interpreted as typical. However, areas of research shown to be of special interest by year-1 studies will be addressed. For example, studies during year 1 may show that more data are needed to describe the relationship between main channel and backwater dissolved-oxygen concentrations. Collection of these data would be emphasized during year 2.

Objectives are described below. Methods and end products will be similar to those described for year 1 but with modification as required.

OBJECTIVE 1

Repeat monitoring of physical and chemical characteristics in segment 15 (year 1, objective 3). Emphasis will be placed on study of areas where long-term data are needed and in areas shown to be of special concern. Personnel at MWRD and individuals involved in modeling dissolved-oxygen concentrations will be consulted to ensure that the necessary data are being collected.

OBJECTIVE 2

Repeat faunal survey of the stream-fish community at monitoring sites and in segment 15 (year 1, objective 4).

OBJECTIVE 3

Repeat use of the autopsy-based condition assessment to evaluate individual fish and fish populations (year 1, objective 5).

OBJECTIVE 4

Repeat index of biotic integrity analysis at monitoring sites (year 1, objective 6).

OBJECTIVE 5

Conduct laboratory exposure studies with ELS of channel catfish and largemouth bass (year 1, objective 7).

BUDGET YEAR 2, March 1993 - February 1994

An exact estimate of costs for Year 2 cannot be made at this time. Projected total cost will fall within a range of $110,000 to $118,000.

REFERENCES

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Table 1. Preliminary target dissolved-oxygen concentrations and duration of exposure for fluctuating dissolved oxygen experiments.

Treatment	Dissolved-oxygen concentration		
	Daily low (mg/L)	Daily high (mg/L)	Duration of low exposure (h)
1	2	6	8
2	3	6	8
3	4	6	8
4	5	6	8
5	6	6	8

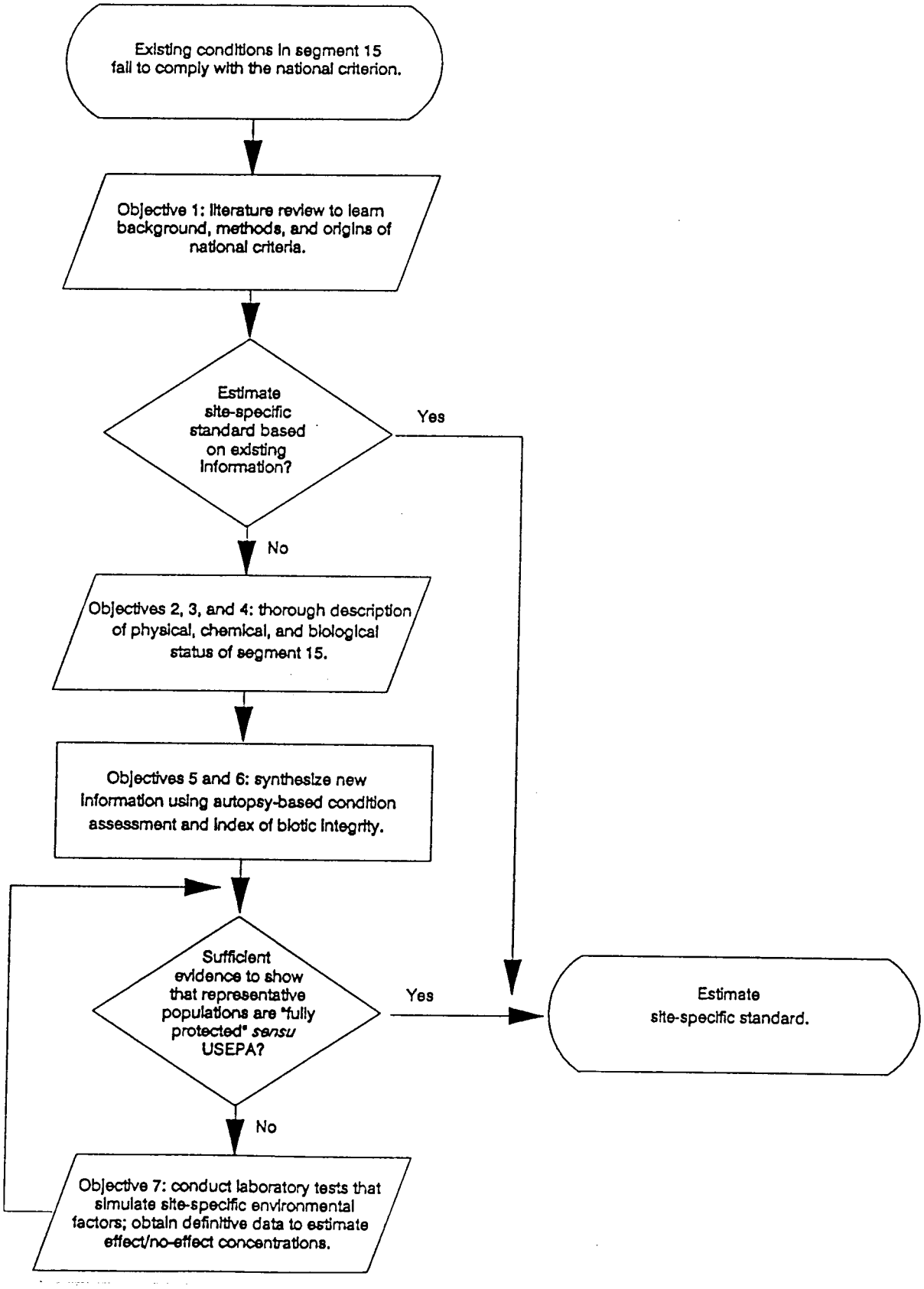

Figure 1. Relationship of objectives to goal of estimating a site-specific standard for segment 15.

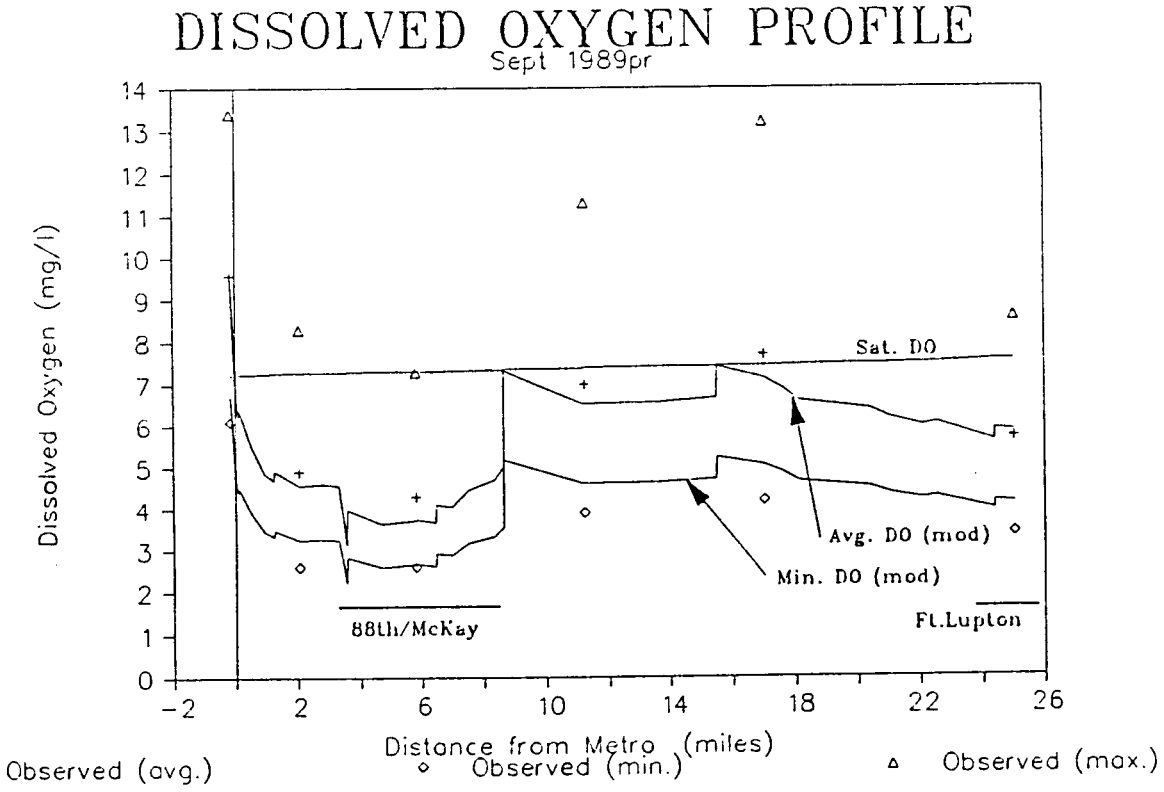

Figure 2. Dissolved oxygen concentration in the South Platte River as a function of distance downstream from the Metro Wastewater Reclamation District.

APPENDIX A: PHYSICAL HABITAT STRATIFICATION PROCEDURES

The following habitat stratification approach is designed to reflect the geomorphic/hydrologic variability of the Upper Colorado River drainage. These habitat evaluation methods are designed to quantify physical variables in such a manner as to provide high resolution relative to fish habitat electivity. The habitat evaluation and data recording procedures are used by both the NW Region survey personnel who concentrate largely on adult fishes collected by electrofishing and research personnel who concentrate on larval forms collected largely by seining. With minor modifications, the system will interface with procedures used by FWS (Colorado River Fisheries Project) and is computer compatible with the MANAGE database system. Figure A-1 depicts most habitat descriptors in a generalized river reach.

For each sample collected at an intensive, intervening, or special site, a "primary habitat" designation is assigned. Primary habitats are designed to reflect largely riverine geomorphic variation. Within each primary habitat, a variety of "specific habitat" types exist, which reflect the variability of discharge and flow. For each primary-specific habitat pair, substrate, cover, current velocity, water temperature, depth, and area sampled are determined.

Strata Definitions:

I. Primary habitat

MC (Main Channel). That section of a river which carries the greatest part of the flow during all seasons.

CC (Chute Channel). High gradient secondary channel with high velocity and large substrate size in the upper section typically followed by a deep pool. Lower section is usually characterized by decreased velocity and small substrate size.

SC (Side Channel). A secondary channel which may carry appreciable flow and provide either low velocity or near stagnant habitat, particularly in the lower section. Gradient and velocity are low and similar to main channel. Side channels are usually depositional with substrates of small particle size. Emmergent and/or submerged macrophytes frequently abundant.

TS (Tributary Stream). An inflowing permanent or ephemeral stream.

ID (Irrigation Ditch). Man-made diversion from river, used chiefly for irrigation.

IK (Lake). A natural lake or manmade impoundment on a permanently flowing stream.

GP (Gravel Pit). Excavation for gravel mining. May be periodically or permanently connected to river.

RP (Reservoir, Primary). Reservoir on 4th order or larger permanent stream.

RS (Reservoir, Secondary). Reservoir on 3rd order or smaller permanent stream.

RT (Reservoir, Tertiary). Reservoir on ephemeral tributary stream.

ØI (Offstream Impoundment). Excavation isolated from the river channel.

II. Specific Habitat

BA (Backwater). A body of water off the main channel with no measurable velocity, often created by a drop in water level which partially isolates a former secondary channel or by high water levels which flood low-lying areas.

ED (Eddy). Whirlpools or turbulent backcurrents created by obstructions or islands in the channel or by the juncture of two channels below an island.

PØ (Pool). A portion of stream that is deep and quiet relative to the main current.

RI (Riffle). A shallow rapids in open river where the water surface is broken into waves by obstructions or irregular substrate wholly or partially submerged.

RU (Run). A stretch of relatively deep fast-flowing water with the surface essentially nonturbulent.

SH (Shoreline). The shallow, low to negligible velocity waters next to shore.

RA (Rapid). A relatively deep and fast flowing area characterized by standing waves and whitewater caused by channel constriction or obstructions.

RF (Rubble Flat). Quiet water areas of large substrate particle size, with some silt deposition. Typically associated with island heads and chute channels, but may be located elsewhere.

EM (Embayment). Shoreline concavities or depressions often created by shoreline obstruction or irregular substrate and associated with low velocity shoreline backcurrents. Length greater than width at mouth.

CØ (Concavity). Similar to EM except width at mouth greater than length.

IP (Isolated Pool). A backwater pool with access to main channel blocked.

PU (Puddle). Isolated on-shore bodies of water created by falling water levels, not cutoff secondary channels.

III. Substrate

SI (Silt). Fine gritty material that is suspended easily.

SA (Sand). Less than 1/10 inches in diameter. (<3 mm).

CL (Clay). Compacted fine particles in bed form that are not suspended easily.

OR (Organic Debris). Muck derived from dead decaying matter.

GR (Gravel). 3/8 to 3 inches in diameter (3 mm to 76 mm).

RU (Rubble). 3 to 12 inches in diameter (76 mm to 305 mm).

BØ (Boulders). Individual segments of rock larger than 12 inches in diameter (>305 mm).

BE (Bedrock). Large solid masses of rock without individual form.

IV. Cover

V (Vegetation). Living emergent vegetation as cover.

B (Brush). Dead plant material, such as Russian thistle and tamarisk or other brush which may provide cover.

R (Rock). Cover as gravel, rubble and/or boulders (correlated with substrate).

Ø (Overhang). Overhanging cliffs and/or ledges which may shade the water at certain times.

T (Turbulence). Surface disturbance or turbulence which may provide cover.

S (Shade). Cover provided by riparian vegetation which may shade the water at certain times.

D (Debris). Cover provided by accumulations of fine aquatic and/or terrestrial organic matter.

N (None). No observable structure, irregularities, etc.

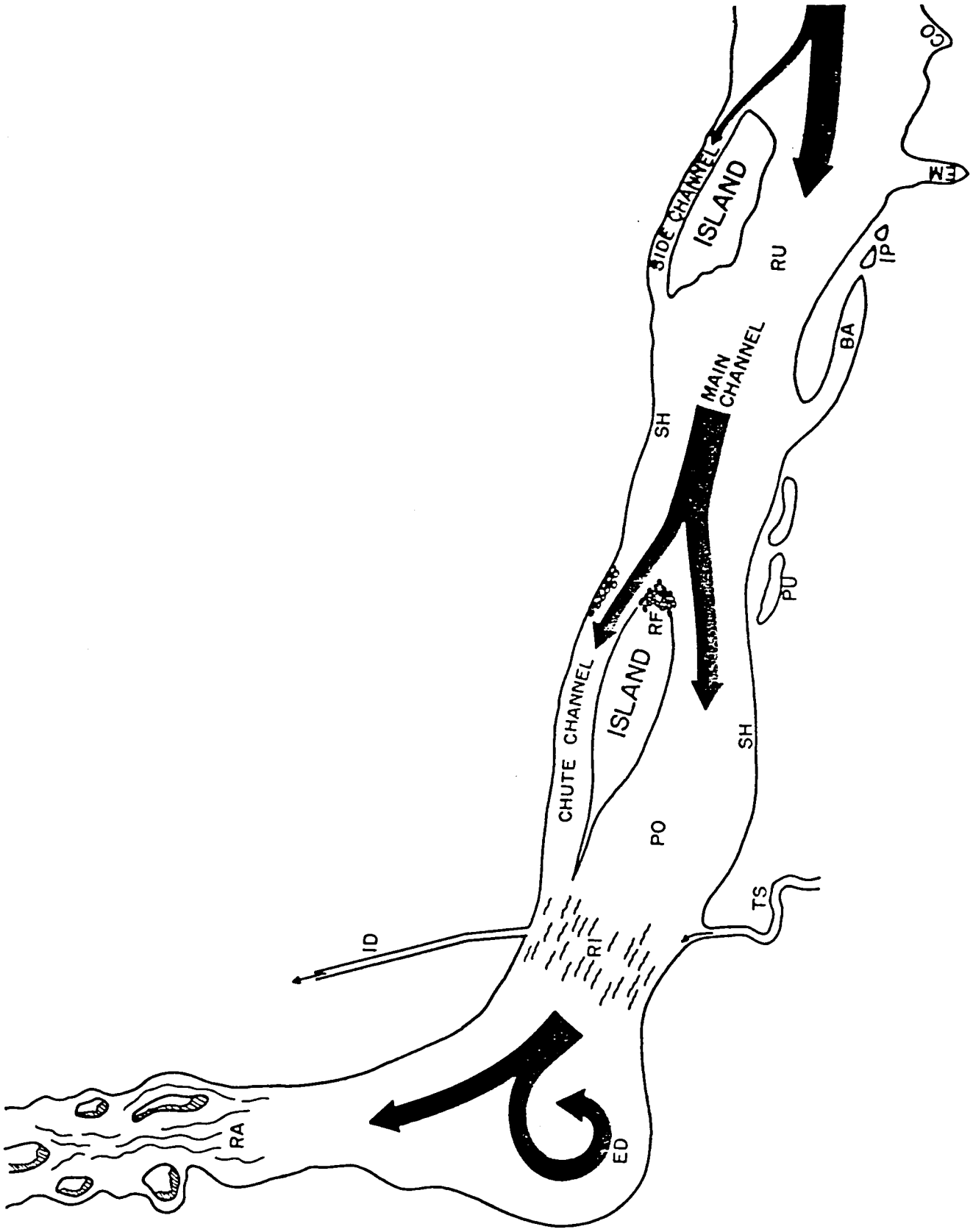

Figure A-1. Generalized river reach in the Upper Colorado River Basin depicting physical habitat descriptors. Refer to text, Appendix A, for strata definitions and codes.

Appendix B: Water Quality Characteristics For Analysis

Item	Detection Limit
Aluminum	0.1
Arsenic	0.001
Barium	0.01
Boron	0.01
Cadmium	0.01
Calcium	0.01
Chromium	0.01
Copper	0.01
Iron	0.01
Lead	0.01
Magnesium	0.01
Manganese	0.01
Mercury	0.001
Molybdenum	0.01
Nickel	0.01
Phosphorus	0.1
Potassium	0.01
Sodium	0.01
Selenium	0.001
Zinc	0.01