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AN INTERAGENCY STREAMFLOW RECOMMENDATION ANALYSIS FOR A PROPOSED ALASKAN HYDROELECTRIC PROJECT[1]

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Abstract.--During 1980-81 an incremental instream flow assessment was performed for the proposed 20 megawatt Terror Lake Hydroelectric Project on northern Kodiak Island, Alaska. This development would reduce average annual discharge by 35 percent near the mouth of the Terror River and augment streamflow by 30 percent in the lower Kizhuyak River, affecting the pink, chum, and coho salmon and anadromous Dolly Varden populations of these rivers. Physical habitat simulation models and fish habitat preference criteria were integrated to arrive at habitat availability indices for various streamflows. Correction factors were applied to these data to assure results portrayed observed field conditions. The final report was utilized by permitting and regulatory agencies in a workshop having an objective of protection or enhancement of the existing fishery resources of the project area while concurrently optimizing hydroelectric power production. The instream flow incremental methodology facilitated arriving at a streamflow regime mutually satisfactory to the regulatory agencies and the electric utility.

INTRODUCTION

Since World War II the City of Kodiak, a large fishing port on Kodiak Island, Alaska, has sought alternative methods for generating electrical power. Electrical energy was, and currently still is, generated by diesel-fired turbines. In the 1950's potential hydroelectric power sites were investigated by Kodiak Electric Association, Inc. (KEA), and one site, Terror Lake, was found only approximately 32 km from the City of Kodiak. A development for the Terror Lake project site was designed in the early 1960's. The project would involve enlarging an existing 109 hectare lake, tapping the newly created 344 hectare reservoir through a power tunnel, thereby diverting water from the Terror River watershed into the Kiżhuyak River watershed where a powerhouse would be located. Although the original scheme for development was deemed too costly for the times, in the late 1970's KEA again asked its consulting engineers to evaluate the Terror Lake project in light of markedly increased diesel costs.

Some engineering refinements were made, and an Application for License to the Federal Energy Regulatory Commission (FERC) was prepared in late 1978. FERC rejected this initial application because of several deficiencies, specifically in the environmental assessment area. KEA contracted with the University of Alaska's Arctic Environmental Information and Data Center (AEIDC) to gather the required additional data to complete a satisfactory environmental assessment.

AEIDC undertook preliminary reconnaissance studies in 1979 (Wilson et al. 1979), during which time several specific fish and wildlife information needs were fulfilled and preliminary groundwork was laid for responding to a more involved question: what would be the quantitative change in fish habitat resulting from streamflow changes in both the Terror River and Kiżhuyak River drainages? As a result of our reconnaissance field efforts, and during further scoping discussions with state and federal agencies as well as FERC, the instream flow incremental methodology (IFIM) was specifically requested by agencies for an instream flow assessment for the Terror Lake project. This methodology was selected specifically because of (1) its capability to assess quantitative change in fish habitat from both decreased and increased streamflows, and (2) FERC environmental staff had determined this method would withstand scrutiny under legal hearing if that were to become necessary. The latter issue was particularly important to this study since the project was to be built on the Kodiak National Wildlife Refuge and interven-

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tion in the FERC licensing process by conservation or other concerned organizations was likely.

FISHERY RESOURCES IN THE PROJECT AREA

The fishery resources of concern in the Terror Lake project area consist of pink (*Oncorhynchus gorbuscha*), chum (*O. keta*), and coho salmon (*O. kisutch*) and anadromous Dolly Varden (*Salvelinus malma*). From the standpoint of their economic importance as well as their contribution to the food resources of the Kodiak brown bear, pink and chum salmon are the primary resources of the drainages. Adult pink and chum salmon return to both drainages to spawn in mid to late summer. In the Terror River an average of approximately 40,000 pink and 5,000 chum salmon return to spawn each year, while in the Kizhuyak drainage approximately 5,000 pink and nearly 10,000 chum salmon escape local commercial fishing gear to return each year. Pinks and chums spawn in the lower segments of both rivers; pink salmon prefer intertidal zones while chums seek areas of upwelling intragravel water flow above the intertidal zone. Of all species, pink salmon are the most important commercial species, sought after by purse seine and gillnet fisheries around the perimeter of Kodiak Island.

Coho salmon are far less abundant, although reliable estimates of adult escapement to both systems are unavailable because of lack of reconnaissance effort by management over the past few years due to persistently poor weather conditions for aerial surveys as well as their sparse distribution in these systems. Perhaps only a few hundred coho escape to each river annually. Anadromous Dolly Varden, on the other hand, are fairly abundant in both systems but only during the summer and fall months. Hundreds, maybe thousands, forage in both drainages throughout the summer, but only a few hundred mature adults will actually spawn in either system during late fall and early winter months. These char feed on drifting pink and chum salmon eggs as well as rearing fry and juvenile coho salmon and Dolly Varden. Anadromous Dolly Varden spawn principally in spring-fed areas, tributaries to the mainstem, or far upriver mainstem segments.

Incubating embryos of all species are present in stream gravels throughout winter months, and fry emergence occurs during late winter and spring. Fry and smolt outmigration occurs during the months of April and May (pink and chum salmon) through June or July (Dolly Varden and coho salmon). The large outmigrating population of pink and chum salmon fry generally peaks during the month of May.

Juvenile Dolly Varden and coho salmon are found in a wide range of habitat types throughout the year in both river systems. During winter they tend to congregate in deeper mainstem areas or in segments of tributaries or backwater areas fed by springflow throughout the ice covered period. During spring and summer juvenile fish are distributed more widely throughout the systems, preferring eddies and pools, side channels and sloughs, and tributaries. Pools created by eddies behind uprooted trees and jams of other debris in the mainstem of both rivers are common mainstem rearing areas.

THE TERROR LAKE DEVELOPMENT SCENARIO

KEA had proposed a minimum postproject flow regime for both rivers based upon recommendations provided by the U.S. Bureau of Commercial Fisheries in the mid-1960's. The project would result in permanent reduction in streamflow in the lower 12.9 km of the Terror River and augmentation in the lower 6.4 km of the Kizhuyak River (Table 1). The Terror Lake hydroelectric project would provide baseload generation of 15 to 20 megawatts for the City of Kodiak, Alaska and surrounding areas. An estimated 76,000 acre-feet of water originating in the Terror River basin would be diverted through an 8 km long tunnel and discharged through a powerhouse located in the Kizhuyak River basin (Figure 1). An additional 42,000 acre-feet of water originating

Table 1--Effects of the Terror Lake hydroelectric project on average monthly streamflow near the mouths of the Terror and Kizhuyak Rivers.

	Terror River Average Monthly Streamflow (cfs)			Kizhuyak River Average Monthly Streamflow (cfs)		
Month	Preproject	Postproject	% Change	Preproject	Postproject	% Change
January	69	62	-10	50	150	200
February	56	65	16	40	150	275
March	50	62	24	40	150	275
April	99	124	25	45	150	233
May	403	239	-41	300	370	23
June	822	417	-49	600	580	-3
July	579	346	-40	500	510	2
August	374	261	-30	450	490	9
September	375	245	-35	225	290	29
October	275	170	-38	160	230	44
November	170	109	-36	70	160	129
December	80	66	-18	50	150	200
Average	279	181	-35	211	282	34

Figure 1--Location of the Terror Lake project area.

in the Kizhuyak basin would be diverted to the powerhouse from three tributary streams to augment the Terror basin diversion. This development would decrease the mean annual discharge in the Terror River basin by 34.7 percent at the river mouth, and would increase that for the Kizhuyak River at its mouth by approximately 30 percent.

INSTREAM FLOW STUDY METHODS

The IFIM makes extensive use of fish habitat suitability criteria and the concept of Weighted Usable Area (WUA). As used in this study, WUA is a quantitative index of the availability of fish habitat at a given streamflow. Extensive hydraulic simulation, as described in Milhous, Wegner and Waddle (1981) yielded stream models capable of predicting physical habitat available under a wide range of streamflow regimes. Descriptions of the methodology are available in several publications (Bovee and Milhous 1978; Trihey 1979, 1980; Stalnaker 1980; Trihey and Wegner 1981; Bovee 1982). While very data-intensive, the incremental method in my opinion is unsurpassed in its capability to examine a multitude of hydro project operation scenarios where river flow will be changed. It enables quantification of fish habitat available at almost any streamflow, thus permitting resource managers or other decision-makers to optimize electric power generation from a hydroelectric production facility while at the same time view trade-offs (or enhancement) in fish habitat.

Aquatic habitat for specified stream discharges was determined principally on the basis of three physical parameters: depth, velocity, and substrate. Application of the incremental methodology is comprised of several steps: (1) field observation and consultation with experts to determine fish species composition and distribution by life history stage within the stream; (2) study site selection using either a critical reach or representative reach approach; (3) field measurement of hydraulic and stream channel characteristics using a multiple transect approach; (4) field observations and measurements to validate or develop habitat suitability criteria (i.e., species preference or tolerance for physical parameters); (5) hydraulic simulation to determine the frequency and spatial distribution of depth-velocity combinations with respect to substrate for unobserved streamflows; and (6) calculation of Weighted Usable Area based upon the results of steps 4 and 5. Trihey (1982) and Baldrige and Amos (1982) provide additional more detailed information on the methodologies utilized in this study.

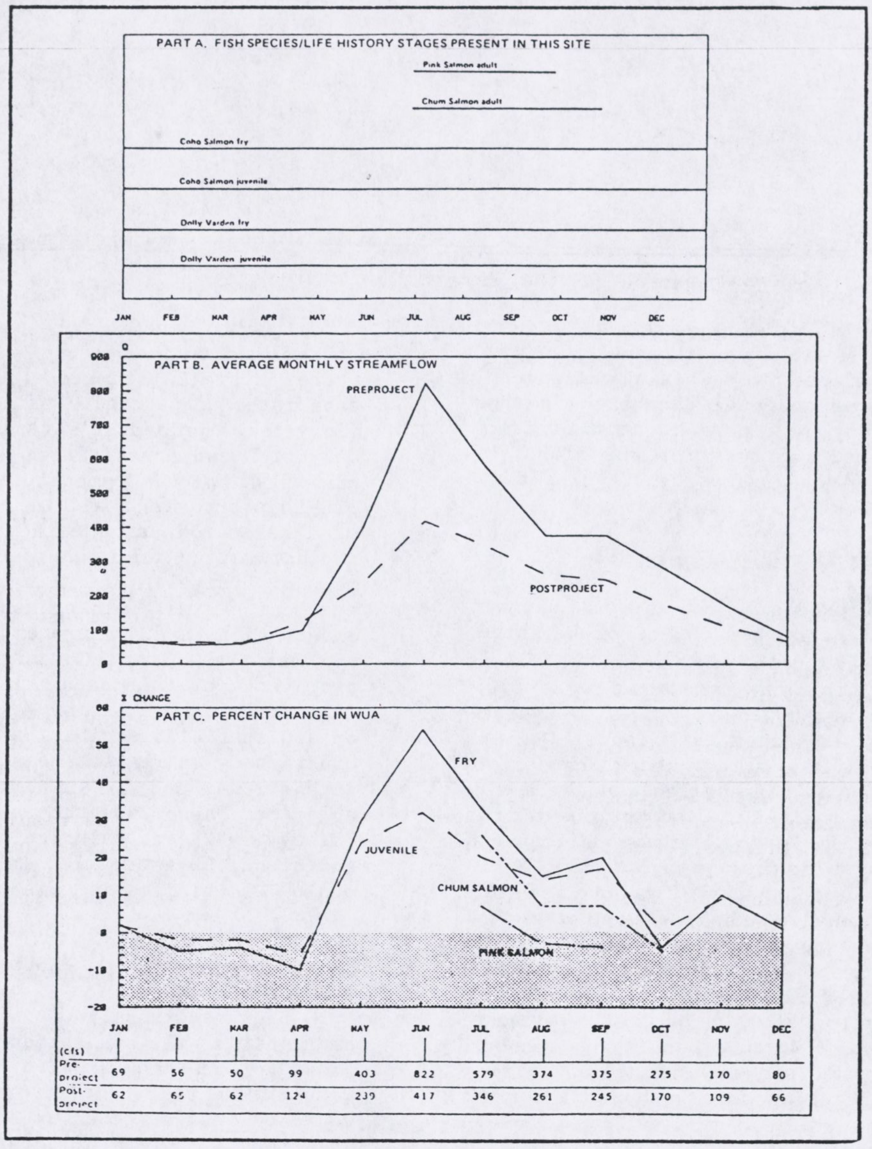
RESULTS

Because streamflows in the Terror River would be significantly and permanently reduced and streamflows in the Kizhuyak River increased, flow regime was the one aspect of riverine fish habitat which would be most affected by the proposed development. This paper, therefore, focuses on flow regime versus fish habitat considerations. The process through which instream flow information was used to help regulatory agencies, the utility, and intervenors to the FERC licensing process attain a mutually acceptable streamflow regime was comprised of three steps: (1) facilitating the decision-making process by design of appropriate display methods for data from the instream flow analysis, (2) critical evaluation of the predicted effects of anticipated changes in flow regime on fish habitat in both drainages, and (3) enhancing the prospects of arriving at a postproject flow regime acceptable to agencies and the utility.

Data Display Formats

The electric utility proposed to deliver a minimum of 1.68 cu m/sec (60 cfs) average monthly streamflow to the Terror River mouth except in April and May, when 2.80 cu m/sec (100 cfs) would be delivered for smolt outmigration. The effects of this altered flow regime on the riverine fishery resources in the project area were evaluated by hydraulic and fish habitat modeling, and the results were displayed in a variety of formats to facilitate ease of interpretation by the individuals we anticipated would review this report. Extensive use was made of graphics to illustrate differences between pre- and postproject situations. Charts were prepared which illustrated pre- and postproject average monthly streamflows and the percent change in fishery habitat--Weighted Usable Area--by species and life history stage (Figure 2). Pre- and postproject Weighted Usable Area data for each month for each species were contrasted and Weighted Usable Area as a percent of stream surface area for each month also was

Figure 2--Summary of project effects on monthly streamflows and Weighted Usable Area at the Terror Gage study reach.



(cfs)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Pre-project	69	56	50	99	403	822	579	374	375	275	170	80
Post-project	62	65	62	124	239	417	346	261	245	170	109	66

portrayed. A graphic portrayal of the study reach was provided with accompanying illustrations of the stream channel cross sections at all study reaches. The calibration discharges were plotted on the stream channel cross sections to permit visual comparison of low, medium, and high flows in terms of top width or wetted perimeter. Summary tables were also prepared illustrating at each study reach the pre- and postproject Weighted Usable Area for each species and life history stage. These tables also included extrapolation factors to expand the predictions at a specific study site to the entire segment of river that that study site represented (Table 2). By summing river segment Weighted Usable Areas, a comprehensive view of project effects upon all life history segments of each fish species in each river system could be realized (Table 3).

Evaluation of Effects Predicted by Models

The second part of the analytical process involved relating study results to actual field conditions. An essential component of any aquatic/fishery modeling study should be the careful interpretation of modeling results by experienced field biologists. In this study, we felt it extremely important to critically evaluate all data generated by the hydraulic and fish habitat models. Actual field conditions are not always well duplicated by mathematical or other models, if at all. Thus, we asked ourselves: do we believe the results, and if not, what are the possible explanations for any apparently anomalous model predictions. We felt, therefore, that some subjective interpretation of habitat data generated by the incremental method models was in order.
The following conditions were subjectively factored into the overall instream flow assessment report.

Groundwater Contribution to Surface Runoff

Changes in fish habitat resulting from project-induced streamflow alteration can be moderated, or exacerbated, by the influence of springflow or groundwater seepage. During periods of low surface flow, springs can maintain water flow through streambed gravels and, therefore, favorable dissolved oxygen and thermal regimes. These areas may not be significantly influenced by surface streamflow change resulting from project operation and, therefore, would act as a reservoir of fish habitat remaining even under the more adverse postproject situations.

Actual Habitat Use by Spawning Salmon

Weighted Usable Area indices calculated for a specific species and life history stage in a given river segment are a function of habitat criteria and physical conditions. This index does not imply that that specific river segment was used to capacity by that species. For example, the availability of 1,000 Weighted Usable Area units in the upper drainage of the Terror River system could not be assumed to be as important to spawning pink salmon as 1,000 Weighted Usable Area units in the lower 1.6 km. In this lower, intertidal reach of the Terror River, our field crews observed pink salmon spawning in nearly all available habitat. Pink salmon made noticeably less use of habitat for spawning in the middle and upper river segments, even though habitat was available in considerable quantity (in terms of depth, velocity, and substrate characteristics). Distances between redds were consistently greater at upstream spawning areas than in the lower river. Clearly, a higher redd density per unit of Weighted Usable Area existed in the lower km of the Terror River (and also in the Kizhuyak River) than at any upstream location.

Table 2--Summary of project effect on fish habitat of the Terror Gage Study reach and the Terror River Segment that it represents.

Month	Spawning WUA						Fry Rearing WUA						Juvenile Rearing WUA					
	Pink Salmon			Chum Salmon			Coho Salmon			Dolly Varden			Coho Salmon			Dolly Varden		
	Pre	Post	%Δ	Pre	Post	%Δ	Pre	Post	%Δ	Pre	Post	%Δ	Pre	Post	%Δ	Pre	Post	%/
January							11,636	11,795	1	17,779	18,215	2	23,440	23,997	2	23,495	24,043	2
February							12,115	11,615	-4	18,797	17,937	-5	24,216	23,703	-2	24,248	23,754	-2
March							12,186	11,795	-3	19,200	18,215	-5	24,450	23,997	-2	24,471	24,043	-2
April							10,631	9,357	-12	16,455	15,047	-9	22,058	20,813	-6	22,161	20,930	-6
May							7,580	10,067	33	12,262	15,456	26	16,724	20,748	24	16,961	20,983	24
June							4,618	7,340	59	8,014	11,965	49	12,440	16,322	31	12,533	16,560	32
July	23,276	24,802	7	14,795	18,600	26	6,000	8,819	47	11,825	13,935	18	15,683	18,722	19	15,869	18,959	19
August	24,613	23,854	-3	18,334	19,544	7	8,183	9,510	16	13,042	14,853	14	17,667	20,072	14	17,903	20,333	14
September	24,605	23,530	-4	18,326	19,618	7	8,160	9,943	22	13,012	15,299	18	17,629	20,636	17	17,864	20,881	17
October				19,453	18,576	-5	9,467	8,733	-8	14,729	14,704	-.2	19,653	19,790	.7	19,919	19,931	.1
November							8,733	9,948	14	14,704	15,650	6	19,790	21,521	9	19,931	21,634	9
December							11,706	11,612	-.8	17,460	17,889	2	23,180	23,627	2	23,251	23,679	2
ΣWUA[1]	72,490	72,190	-.4	70,910	76,340	8	111,020	120,530	9	177,280	183,170	7	236,930	253,950	7	238,610	255,730	7
Avg. Mo. WUA	24,160	24,060		17,730	19,090		9,250	10,040		14,770	15,760		19,740	21,160		19,880	21,310	
Extrapolation[2] Factor	6.3	6.3		6.3	6.3		6.3	6.3		6.3	6.3		6.3	6.3		6.3	6.3	
R. Segment ΣWUA	456,700	454,800	-.4	446,700	480,900	8	699,400	759,300	9	1,116,900	1,191,800	7	1,492,700	1,599,900	7	1,503,200	1,611,100	7
R. Segment Avg. Mo. WUA	152,200	151,600		111,700	120,300		58,300	63,300		93,100	99,300		124,400	133,300		125,200	134,300	

River segment represented by Terror Gage = 1.2 mi.

1. Accumulative WUA is the summation of monthly WUA values for the time period that the designated species/life stage is occupying the representative reach; 12 months rearing, July - September pink spawning, and July - October chum spawning.

2. Extrapolation factor is the multiplier used to apply WUA values to the entire river segment represented by the study reach. It is simply the length of the river segment being represented by the study reach in feet, divided by 1,000.

River Segment	Flow Regime	Spawning WUA								
		Pink Salmon			Chum Salmon			Combined		
		Σ WUA	Net Change	% Change	Σ WUA	Net Change	% Change	Total WUA	Net Change	% Change
Upper Terror	Pre	278,200						278,200		
	Post	365,000	86,800	31.2	–	–	–	365,000	86,800	31.2
Bear Meadow	Pre	121,000			82,700			203,700		
	Post	170,400	49,400	40.8	114,000	31,300	37.8	284,400	80,700	39.6
Log Jam	Pre	521,400			529,700			1,051,100		
	Post	403,500	-117,900	-22.6	420,100	-109,600	-20.7	823,600	-227,500	-21.6
Terror Gage	Pre	456,700			446,700			903,400		
	Post	454,800	-1,900	-0.4	480,900	34,200	7.7	935,700	32,300	3.6
Mainstem Total	Pre	1,377,300			1,059,100			2,436,400		
	Post	1,393,700	16,400	1.2	1,015,000	-44,100	-4.2	2,408,700	-27,700	-1.1

River Segment	Flow Regime	Fry Rearing WUA								
		Coho Salmon			Dolly Varden			Combined		
		Σ WUA	Net Change	% Change	Σ WUA	Net Change	% Change	Total WUA	Net Change	% Change
Upper Terror	Pre				1,875,700			1,875,700		
	Post	–	–	–	2,044,700	169,000	9.0	2,044,700	169,000	9.0
Bear Meadow	Pre	538,600			879,600			1,418,200		
	Post	565,100	26,500	4.9	965,800	86,200	9.8	1,530,900	112,700	7.9
Log Jam	Pre	1,731,900			2,524,300			4,256,200		
	Post	1,816,800	84,900	4.9	2,669,500	145,200	5.8	4,486,300	230,100	5.4
Terror Gage	Pre	699,400			1,116,900			1,816,300		
	Post	759,300	59,900	8.6	1,191,800	74,900	6.7	1,951,100	134,800	7.4
Mainstem Total	Pre	2,969,900			6,396,500			9,366,400		
	Post	3,141,200	171,300	5.8	6,871,800	475,300	7.4	10,013,000	646,600	6.9

River Segment	Flow Regime	Juvenile Rearing WUA								
		Coho Salmon			Dolly Varden			Combined		
		Σ WUA	Net Change	% Change	Σ WUA	Net Change	% Change	Total WUA	Net Change	% Change
Upper Terror	Pre				2,392,100			2,392,100		
	Post	–	–	–	2,654,700	262,600	11.0	2,654,700	262,600	11.0
Bear Meadow	Pre	1,145,800			1,151,000			2,296,800		
	Post	1,292,500	146,700	12.8	1,298,800	147,800	12.8	2,591,300	294,500	12.8
Log Jam	Pre	3,022,700			3,073,200			6,095,900		
	Post	3,174,700	152,000	5.0	3,229,200	156,000	5.1	6,403,900	308,000	5.1
Terror Gage	Pre	1,492,700			1,503,200			2,995,900		
	Post	1,599,900	107,200	7.2	1,611,100	107,900	7.2	3,211,000	215,100	7.2
Mainstem Total	Pre	5,661,200			8,119,500			13,780,700		
	Post	6,067,100	405,900	7.2	8,793,800	674,300	8.3	14,860,900	1,080,200	7.8

Table 3--Summary of project effects on WUA in the Terror River basin.

Flood-flows and Scour vs Low Flow and Dessication

The change in basin-wide Weighted Usable Area indices from pre- and postproject situations were representative only of average-year streamflows. During periods of abnormally high or low flow, project operation could have different effects on spawning pink salmon. In order to better visualize the natural variability of habitat conditions in the Terror and Kizhuyak rivers and the effects that project operation might have on these phenomena, Weighted Usable Area indices were determined specifically for pre- and postproject wet and dry years. In other words, during dry periods project withdrawals from the Terror River system may greatly exacerbate an already stressed situation for adult spawners by reducing streamflows even further, crowding spawners and perhaps causing redd superimposition. In this situation, habitat for spawning salmon would be expected to be reduced significantly during low-flow periods. During high-flow periods, however, the proposed streamflow withdrawals during spawning months could be beneficial, both from the standpoint of increasing Weighted Usable Area (primarily attributed to the reduction in mean column velocities) and reducing the potential for streambed scour and the resultant high egg or alevin mortality.

Other Adjustments to Model Predictions

In addition to the above factors, other aspects of our computer model output was scrutinized in light of preference by spawning chum salmon for intragravel water upwelling and the effects of the project on habitat conditions during winter incubation of salmonid eggs. AEIDC's instream flow assessment team initially evaluated the results from the hydraulic and fish habitat models in light of their field experience. Factors such as intragravel water upwelling, cover, water temperature, river channel scour, backwater effects, and springflow were considered in association with the WUA indices. Thus, conclusions in our final report were derived from the instream flow model output adjusted (or, in most cases, bolstered) by these unmodelled but biologically significant factors.

Report Conclusions

AEIDC's final report (Wilson et al. 1981) was prepared and distributed by KEA to FERC and the many state and federal agencies responsible for granting permits or permit review. The results of the incremental instream flow assessment provided a working document with which a negotiated settlement of a potential controversy was expeditiously reached. During low-flow periods, the postproject streamflows would reduce spawning habitat in the Terror River drainage, but would not affect fishery habitat in the Kizhuyak River system. During high-flows the Terror Lake reservoir would reduce the intensity of peak daily streamflows, thereby reducing the severity and frequency of streambed scour in spawning areas in the lower mainstem Terror River. The project would have an insignificant effect on peak flows in the Kizhuyak River. The bottom line was that postproject flows would have little effect on fish.

The reason for this conclusion was that in almost all years, wet, dry, or average, the utility would affect only the upper one-third of the Terror watershed. Recurring, persistent, and extensive precipitation on Kodiak Island would maintain streamflows in the lower watershed where the entire fishery resource is located. Even though KEA would guarantee 1.68 cu m/sec (60 cfs) in the lower river for spawning, far in excess of that amount would flow merely from runoff in the lower two-thirds of the basin. In the Kizhuyak River, a continuous 4.90 cu m/sec (175 cfs) over and above natural streamflows would be discharged from the powerhouse, having no consequence to fish in that river. The principal question still remaining for resource managers: what is the absolute minimum acceptable streamflow regime for the Terror River? We know 1.68 cu m/sec (60 cfs) is far too low for spawning, and we also know that climatic conditions would probably preclude that situation in most years. Nevertheless, what minimum flow regime should be recommended to FERC for licensing? That question led our study team to the third step in the recommendation process.

FINAL RECOMMENDATIONS: AN INTERAGENCY WORKSHOP

So you have a report--now what? The instream flow study completed by AEIDC for KEA was a product containing extensive numerical and interpretive material. Our work generated a complex set of results which, in order to be understood by someone other than a member of the study team, had to be examined carefully. It appeared to us unlikely that agency personnel would either have the time or the background to adequately comprehend the study or to prepare comments for FERC regarding the adequacy or inadequacy of the electric utility's instream flow study. Similar sentiments were voiced by many agency representatives; we, therefore, suggested that a task group be convened so that the assigned review staff of concerned agencies could together become well versed with the instream flow assessment methodology employed and the types and significance of data generated from the study. This forum also would provide an opportunity for agencies to interact to arrive at a mutually satisfactory streamflow regime which protected fishery habitats in both systems yet did not compromise power production desired by KEA.

Attending the four-day session were representatives of several agencies as well as staff scientists from AEIDC (hydraulic engineering, fishery biology) to interpret data or to explain results. Invited by the USF&WS were individuals from the Cooperative Instream Flow Service Group (IFG) to provide additional analytical support and comment. The principal goal of the working session was to arrive at an agency consensus on an acceptable minimum postproject streamflow regime--at least at the biological staff level. The interagency group felt that various alternatives to the streamflow regime originally proposed by the utility should be examined, and a concensus streamflow regime forwarded to the utility and to FERC. KEA was not present at this workshop, but the power production tradeoffs from various alternative streamflows were known by the workshop participants, and the utility's contracting engineers were consulted periodically throughout the workshop for various input. Also, the utility paid for the original study and already were well-versed on the results and their implications.

Several limitations and assumptions were agreed to by all at the beginning of the workshop. It was determined that because of its economic importance and the large size of runs in both drainages, pink salmon were selected to be the indicator species for review of alternative streamflow regimes. Also, a single study site was selected to be representative of the overall hydraulic and habitat characteristics of the Terror River system: the Terror Gage study site. This study site contained representative spawning and rearing conditions found in the entire drainage and included a prime pink salmon spawning area. The Kizhuyak Gage study site was similarly selected for that drainage. Thus, by limiting discussions to a single study site and a single species, the interagency group could complete an analysis of alternative streamflow regimes for both rivers in a timely yet biologically satisfactory manner.

Various tools were made available to the workshop team. Initially the graphs and charts prepared by AEIDC were reviewed and the procedures for adjusting model output were presented. In order to simplify the presentation of the long-term consequences of postproject streamflow regime alternatives, the IFG staff transformed the AEIDC habitat data into time series analyses of project effects based on a 27-year synthetic streamflow record for both river drainages. Pre- and postproject hydrographs for the 27 years of synthetic and measured streamflow record for the Terror Gage and Kizhuyak Gage study sites were reviewed. These graphs showed the natural state in the Terror River and the long-term consequences of this project on the existing streamflow patterns. Using the 27 year period of record, the IFG staff graphically displayed the long-term consequences of augmented streamflows on pink salmon spawning habitat in the Kizhuyak drainage. Trihey (1982) explains the technique utilized to generate these time series Weighted Usable Area data.

No long-term detrimental effects were noticed for the Kizhuyak system. A similar data portrayal for the Terror River system illustrated the long-term effects of the postproject 1.68 cu m/sec (60 cfs) minimum as well as the consequences of establishing a different minimum flow. Four time series analyses of pink salmon spawning Weighted Usable Area contrasted preproject, proposed postproject, and a series of alternative postproject minimum streamflow regimes: 7.00 cu m/sec (250 cfs), 5.60 cu m/sec (200 cfs), 4.20 cu m/sec (150 cfs), and 2.80 cu m/sec (100 cfs). The interagency workshop group felt that the long-term consequences of the proposed postproject regime of 1.68 cu m/sec (60 cfs) minimum would reduce pink salmon production to an unacceptable level. Similarly, the establishment of a 2.80 cu m/sec (100 cfs) minimum would result in a Weighted Usable Area (WUA) low threshold judged to be unsatisfactorily low when compared with the preproject WUA mean. The group felt that the long-term low threshold resulting from a 4.20 cu m/sec (150 cfs) minimum would be an acceptable minimum streamflow regime.

The point I wish to make is this: the incremental method quantifies fish habitat available for any streamflow (within the extrapolation limits of the hydraulic models employed). Thus, a variety of alternatives can be explored and compared quantitatively. The method enables a decision-maker to readily appraise the consequences of streamflow changes and render a decision in a minimal amount of time.

The consequences of a reduced streamflow regime in the Terror River were also evaluated for salmonid egg incubation. Fertilized embryos of all four species of salmonid incubate in streambed gravels throughout the period July-April. AEIDC staff biologists familiar with available literature on these species as well as site-specific field conditions developed criteria for pink salmon egg incubation. The IFG staff then transformed this data into a 27 year time series of incubation WUA for pre- and postproject streamflow regimes. Readily visible were the recurrent low WUA values during winter under preproject conditions and the benefits accrued to incubating eggs by a 1.68 cu m/sec (60 cfs) minimum flow. The 27 years of simulated pre- and postproject streamflow data readily illustrated the number of times that midwinter streamflows would drop below the proposed minimum streamflow value. This indicated that considerable overall benefit, in terms of egg incubation, would result from stabilizing midwinter streamflows near 1.68 cu m/sec (60 cfs).

Spawning and egg incubation are events in a fish's life cycle which are intimately related. How could we be assured that the fertilized eggs deposited at a certain spawning streamflow would have sufficient water at a lesser incubation streamflow? The concept "Surviving Weighted Usable Area" was examined by the interagency group. This is discussed as effective spawning area by Milhous (1982). Both high flow (scour) and low flow (dewatering) situations were portrayed for each of four spawning streamflows: 1.68 cu m/sec (60 cfs), 2.80 cu m/sec (100 cfs), 4.90 cu m/sec (175 cfs), and 7.00 cu m/sec (250 cfs). WUA which would "survive" from these spawning flows were then generated from various incubation streamflows. Data were generated using the egg incubation habitat criteria previously mentioned over the 27 year period of synthetic record.

The interagency group analyzed the four situations and concluded that, although flows of 7.00 cu m/sec (250 cfs) would maintain preproject spawning conditions, an incubation flow of 4.48 cu m/sec (160 cfs) would be required in order to maximize survivability. Or, in other words, if salmon spawn at a streamflow of 7.00 cu m/sec (250 cfs), any subsequent flow of less than 160 cfs would result in egg mortality from redd dewatering, thereby negating the production from the 7.00 cu m/sec (250 cfs) spawn. The group concluded that a spawning flow in the range of 4.90 cu m/sec (175 cfs) would complement an incubation flow of 1.68 cu m/sec (60 cfs).

The interagency group's final instream flow recommendation for the Terror River system appeared to be biologically sound for the maintenance of the existing fishery resources, particularly during low-flow conditions: spawning flows should be 4.20-4.90 cu m/sec (150-175 cfs) winter flows 1.68 cu m/sec (60 cfs), and spring smolt outmigration flows 2.80 cu m/sec (100 cfs). While there appeared to be room for small increment streamflow trade-offs in either direction during the spawning period, any streamflow regime significantly less than that concluded by the discussion group would be unacceptable. Thus, it was felt that this minimum regime would be palatable to all agencies concerned with this project, was realistic and attainable, and would not compromise the health of fish stocks in the Terror and Kizhuyak River drainages.

Having arrived at a consensus amongst themselves, state and federal agencies were able to transmit to FERC that, in terms of instream flow, the Terror Lake project was fully evaluated and no mitigation, other than the consensus streamflow regime, would be required for aquatic/fishery impacts. Because of KEA's acceptance of the study as well as the interagency recommendation regarding downstream releases, a negotiated settlement was rather quickly reached between the applicant and the Alaskan resource agencies. Thus, the recommended streamflow regime (Table 4) was made part of an overall agreement between the utility, the U.S. Department of the Interior, the State of

Alaska, and several other intervenors was presented to FERC for attachment to the final environmental impact statement (EIS). The final EIS was circulated, and a license to construct was granted by FERC on September 29, 1981. The project is underway, and a monitoring agreement has been implemented, satisfying the agency mandated follow-up study and monitoring requirements.

The instream flow incremental methodology provided an excellent and widely acceptable tool for quantitatively evaluating the effects of streamflow change relating to the Terror Lake Hydroelectric Project on Kodiak Island. The data products from this instream flow assessment permitted sound and orderly decision-making by those concerned with the environmental effects of this project. Future users of this method in Alaska should understand its limitations, and the need for creative use and adaptation to each specific circumstance. Quantitative modeling of aquatic habitats should never entirely take the place of the judgement of experienced fishery biologists, but rather these techniques are excellent complementary tools which can be constructively used by fishery biologists in improving their skills of predicting the effects of streamflow or channel change on fish habitat.

An instream flow assessment must be a team effort, involving at least those disciplines of fishery biology, open channel hydraulics, and perhaps such capabilities as sediment transport or thermal modeling. In Alaska, where many river systems are ungaged, where climate stations are often widely dispersed or completely nonexistent, and where often only limited knowledge of fishery resources is available, the difficulty of the task of the instream flow assessment team is compounded due to lack of necessary background data. In such cases, I judge it necessary to spend sufficient time gathering these kinds of baseline data before undertaking the instream flow study itself. Also, such assessments must usually involve the employment of capable streamflow pattern modeling expertise to develop synthetic hydrographs or other hydrologic data of key importance to the successful completion of hydraulic modeling. Whether the assessment is a simple, one study site evaluation or a more complex study such as that conducted for the Terror Lake project, the instream flow incremental methodology, in my opinion, is unsurpassed in its utility as a decision-making tool for the comprehensive and wise evaluation of environmental effects of streamflow change on fish habitat.

To protect existing pink and chum salmon resources of the Terror River, Kodiak Electric Association, Inc. will make the necessary releases from Terror Lake reservoir to ensure that instantaneous streamflows at the Terror Gage No. 15295700 do not fall below the following values during reservoir filling and thereafter during project operation:

Month	Minimum Streamflow	Biological Justification
January	60 cfs	Incubation
February	60 cfs	Incubation
March	60 cfs	Incubation
April	100 cfs	Outmigration
May	150 cfs	Outmigration
June	150 cfs	Outmigration
July	150 cfs	Spawning pink salmon, chum salmon
August	150 cfs	Spawning pink salmon, chum salmon
September	150 cfs	Spawning pink salmon, chum salmon, coho salmon, Dolly Varden
October	150 cfs	Spawning pink salmon, chum salmon, coho salmon, Dolly Varden
November 1-15	100 cfs	Spawning coho salmon, Dolly Varden
November 16-30	60 cfs	Incubation
December	60 cfs	Incubation

Natural streamflows in the Terror and Kizhuyak Rivers will be maintained during project construction.

Table 4--Final consensus streamflow regime for the Terror River.

ACKNOWLEDGEMENTS

The Terror Lake instream flow study was funded by Kodiak Electric Association, Inc. (KEA). The success of this study is largely due to the cooperation and interest shown by David S. Nease, manager of KEA. Recognition is also due to many co-participants in this effort from the Arctic Environmental Information and Data Center. I also thank many scientists with the U.S. Fish and Wildlife Service (USFWS) and the Alaska Department of Fish and Game for assistance in study design and data analysis. The firm Simons, Li and Associates conducted thermal modeling and river mechanics studies, and the U.S. Geological Survey provided streamflow data. Special thanks are extended to Dr. Clair B. Stalnaker and Norval Netsch, USFWS, and E. Woody Trihey for critically reading and offering comments to improve this paper.

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[1992]

INSTREAM FLOW
INCREMENTAL METHODOLOGY
IF 200 OVERVIEW
USING VIDEO FORMAT

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PROFESSIONAL PAPER

INSTREAM FLOW INCREMENTAL METHODOLOGY
IF 200 OVERVIEW
USING VIDEO FORMAT

Submitted by
Jennifer L. McGraw
Department of Fishery and Wildlife Biology

In partial fulfillment of the requirements
for the degree of Master of Science
Colorado State University
Fort Collins, Colorado
Spring 1992

COLORADO STATE UNIVERSITY

March 18, 1992

WE HEREBY RECOMMEND THAT THE PROFESSIONAL PAPER AND PROJECT PREPARED UNDER OUR SUPERVISION BY JENNIFER L. MCGRAW ENTITLED INSTREAM FLOW INCREMENTAL METHODOLOGY, IF200, AN OVERVIEW, AND A VIDEO PRESENTATION "IFIM AN OVERVIEW" BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee on graduate work

Dr. Robert J. Behnke

Professor Eugene Decker

Dr. William Marlatt

Jonathan Taylor

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APPENDIX A

PROPOSAL FOR
IFIM OVERVIEW VIDEO FOR IF200 LECTURE SERIES

BY JENNIFER MCGRAW

PROPOSAL: To povide a video format overview of IFIM to be used as an IF 200 introductory segment.

SUBMITTED TO: Riverine and Wetlands Ecosystems Branch, NERC of the U.S Fish & Wildlife Service and Graduate Committee in Fish and Wildlife at CSU.

PROBLEM STATEMENT/JUSTIFICATION: The U.S. Fish & Wildlife Service needs an overview of IFIM for appropriate audiences to provide an introduction to the lecture series.

PROJECT OBJECTIVE:

1. To fulfill graduate studies obligations for a Plan B Masters Degree; to include a video and supplement professional paper.
2. To inform class attendees, primarily made-up of biologists and engineers who are associated with water management, of IFIM's capabilities and limitations. To perform an IFIM study training requires instruction far beyond this video.
3. To provide an overview of what the class attendees can expect to learn in IFIM.
4. To help water managers evaluate the feasability of an IFIM study.

PRODUCT DESCRIPTION: A 20-25 minute video tape overview of the IFIM models, with accompanying professional paper.

PROJECT PERSONNEL: Jenny McGraw, producer for the video, Julie Winchester, technical director, Shawn Winchester, graphics, Dr. Robert Behnke, CSU Fish & Wildlife Dept. major advisor, Professor Eugene Decker, CSU Fish & Widlife Dept. advisor, Dr. William Marlatt, CSU Earth Resources, outside dept. advisor and Jonathan Taylor, U.S Fish and Wildlife Service Consultant.

SCHEDULE

Dates	Deliverables	Reviewed By
October 3, 1991	Proposal	Comm., FWS
October 15, 1991	Outline	FWS
October 31, 1991	Lit. review	Comm.
November 28, 1991	Document	Comm., FWS
December 20, 1991	Story Board	FWS
March 1, 1992	Video Draft	FWS
April 4, 1992	Final Product	Comm., FWS

PROPOSED BUDGET:

Recording time charged at $20.00 per hour plus mileage. Equipment rental, operator and studio at $110 per hour.

Live footage estimate of 10 hours

Editing: appx. 1 hour per edit with an estimation of 4 edits per minute charged at $25.00 per hour.

Graphics charged at $25.00 per hour

Mileage charged at $ .25 per mile

Air time charged at $65.00 per hour

Approximate estimate of time and charges:

10 graphics X 4 hours X $25.00/hr.	$ 1,000.00
editing:edits/min X 10 hours X $25.00	1,000.00
travel appx 240 miles X $ .25	60.00
air appx. 2 hours X $65.00	130.00
equipment and staff X 14 hours	1,820.00
	$ 4,010.00

ACKNOWLEDGEMENTS

The IFIM Overview video has been the result of a conglomeration of field work, in both an IFIM study and video, study of fish ecology, the IFIM and the people involved with it; teachers and students alike, literature read, and many, many hours of video application, both in the field and in the lab.

Projects of this magnitude do not come in isolation. I am very grateful to many individuals and groups for helping me with this effort. Dr. Robert J. Behnke (CSU, Dept. of Fish & Wildlife) taught me, among other things, the difference between deterministic and stochastic situations. He also pointed out that all the proven science in the world would not necessarily change ones opinion which they've taken a lifetime to form, and to have the wisdom to treat such situations with respect. I will always be thankful to Professor Eugene Decker (CSU, Dept. of Fish & Wildlife) who made me aware of "congruent and incongruent changes" and the magic of "Bold, Colorful, and Simple". Dr. William Marlatt (CSU, Dept of Earth Resources), in teaching me how to prepare an E.I.S. provided me with the answer to nearly everything: "It depends." Jonathan Taylor (USFWS - NERC) dared to journey where no one else would as my mentor and council from the U.S. Fish & Wildlife Service's National Ecology Research Center to assure that the information transfer was correctly represented state-of-the-art technology. Ken Bovee (USFWS - NERC) who showed me the world through IFIM by involving me in snorkeling the South Platte River for several weeks of verification studies.

The video technician and much of the creative talent goes to my dear friend Julie Winchester of CIRA/NPS who spent many overtime hours working on this project. Without her, none of this would have been possible. I am also appreciative of Shawn Winchester, for his exceptional work on the graphics which added so much to the video. In the same vein, Dale Crawford of NERC - USFWS also contributed essential graphics at break-neck speeds so we could make our deadline.

Thanks goes to Steve Riley, a Phd in fish ecology who put in his time editing script as well as contributing vocals to the voice of John Wesley Powell.

Special thanks goes to Lee Lamb, Clair Stalnaker, and Jim Henricksen of the USFWS - NERC for editing contributions, Bureau of Reclamation and the Colorado Division of Wildlife for contributing video footage.

Finally, but no less importantly are the unsung heroes who were there when I needed them most; both for moral support and as babysitters for my daughter Jessica who emerged in the middle of this three year process to challenge and grace us all. They are my husband, Ric Eversole, my parents Hersh and Jan McGraw and Mary Arnesen, the official babysitter.

INSTREAM FLOW INCREMENTAL METHODOLOGY:

AN OVERVIEW

Presented by:

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

Produced by:

Jennifer L. McGraw

Written by:
Jennifer L. McGraw

Narrated by:
Opening shot: Jennifer McGraw
John Wesley Powell: Steve Riley
Script: Julie Winchester

Colorado State University
Department of Fishery and Wildlife Biology
Fort Collins, Colorado 80523

"You could not step twice into the same river; for other waters are ever flowing on to you"

Heraclitus C.540-C.480 B.C.

IF 200 OVERVIEW

INTRODUCTION

The high political profile and scientific problems water managers face today have increased the demand for instream flow training. In response, the U.S. Fish and Wildlife Service is developing additional training techniques for Instream Flow Incremental Methodology (IFIM) using video format. The first video tape for IF200, IFIM: An Overview, will introduce managers to the fundamentals of the IFIM process. This overview tape serves two necessary purposes:

First, this video will help water managers decide if IFIM is applicable to their specific problems before committing the resources for training in IFIM. Second, this video will make users aware of the training and the information needed to properly conduct an IFIM study.

The IFIM is made up of a variety of models and each application varies depending upon the user's needs and the models selected. Therefore, this overview will introduce viewers to water use definitions, give a brief history of flow models and the development of IFIM, and provide a summary of the further training necessary to be proficient at using the IFIM for habitat studies. The video includes a four phase process for applying the IFIM: 1) the negotiation and planning phase, 2) the habitat simulation phase, 3) the alternatives analysis phase and 4) the resolution and negotiation phase.

FISH IN RIVERS

Unaltered rivers are complex, dynamic, self-adjusting physical systems which contain some degree of balance or equilibrium between the forces of flowing water and the resistance to erosion of channel materials (Richards 1982). Since the ecology of lotic organisms may be closely linked to the physical characteristics of the rivers they inhabit (Statzner et al. 1988; Poff and Ward 1989), it is important that we maintain the natural dynamic equilibrium of river systems. Unfortunately, man's activities have caused drastic physical and biological changes in many rivers (Baxter 1977; Ward and Stanford 1979; Williams and Wolman 1984).

Fish species have evolved so as to require specific habitat conditions in which to reproduce, feed, and mature, and these requirements generally change during a fish's life. The shape of the stream channel, the composition of the sediment, water temperature and quality, and terrestrial and aquatic vegetation are some of the habitat characteristics that affect fish populations.

Riverine fish habitat is also strongly dependent on the flow regime. Flows in rivers vary naturally depending on the hydrologic cycle and local climate. Flows can also vary due to manmade hydraulic controls and changes in water demands (Hunter 1991), and these regulated flows may have a profound effect on the quantity and quality of fish habitats. Regulated flows may cause the depletion of native species for a number of reasons, including competition from other species better adapted to the altered environments of regulated rivers.

Water resource managers are faced with a complex set of problems including maintaining fish habitat in relatively unaltered riverine systems, restoring habitat necessary for fish in regulated rivers, and meeting recreational and municipal flow requirements which are often inconsistent with ecological needs. This must be accomplished within the ever changing political guidelines provided by both state and federal regulations.

WATER LAWS AND POLICIES

Water is a renewable resource producing a variety of benefits. Though by law water is considered real property, what is allocated is its use, - the right to take water and put it to some beneficial use over a period of time (Goldfarb). For example, the National Water Commission's accepted water "requirements" include drinking, cleaning, fire fighting, and other essential uses (Trelease and Gould 1986). However, by policy these are expanded to a host of other uses including power generation, irrigation, recreation and ecological applications.

Water use consists of (1)intake or diversionary uses, (2)onsite uses, and (3)instream or flow uses (Goldfarb 1988). Intake uses include water for domestic, agricultural, and industrial purposes-uses that actually remove water from its source. Onsite uses consist mainly of water consumed by wetlands and estuaries, or evaporation from the surface of water bodies, and recharge of the groundwater system which supplies riparian vegetation and adjacent unirrigated crops. Wildlife also consumes water onsite. Instream flow uses include water for recreation, fish and wildlife habitat, navigation, waste dilution and generating hydroelectric power (Goldfarb 1988).

Water rights are primarily granted by the states. To file a water right, the water user must show a beneficial use for acquiring that right. In the eastern United States, water is allocated according to riparian rights. People with property adjacent to a stream or lake are entitled to use it. In the arid west, water is allocated by prior appropriation laws reflecting the old mining claim "first in time, first in right" (Goldfarb 1988). Those who first put the water to some beneficial use maintain first priority rights. Other aspects of the appropriation doctrine include use or lose provisions and proof of beneficial use; usually by constructing diversion works and actually diverting water. This was a big hurdle in getting instream flow recognized as a beneficial use (Bovee 1992).

In 1893, John Wesley Powell's observation of the West's limited resources caused him to address the supply and demand problem in a speech to the Los Angeles National Irrigation Congress. "Gentlemen, it may be unpleasant for me to give you these facts. I hesitated a good deal but finally concluded to do so. I tell you, gentlemen, you are piling up a heritage of conflict and litigation of water rights, for there is not sufficient water to supply the land."(Fradkin 1988). Powell was contemplating the competition building between developers and farmers at the time. Little regard was given to the, then remote, possibility that water would become so scarce as to not sustain the aquatic biota. However, this is the situation facing many water managers today.

Water is essential to life. Balancing water supply and demand is of the utmost importance. When water is plentiful, demands are easily met. When demand exceeds supply, competition for limited water can become intense among municipal, agriculture, recreational, and environmental users.

National attention was first focused on this issue in 1975 by the National Water Assessment Committee. The U.S. Fish and Wildlife Service assumed the responsibility of assessing instream flow impacts resulting from federal water development and permitting.

It was the responsibility of the States to set "standards" for protection. Several methods of developing standard flows for habitat management were used, many of which determined "minimum flow" requirements. These methods have been labeled "standard-setting" because they set a limit to stream flow below which water cannot be diverted without detriment to the biological community.

PREVIOUS METHODS

IFIM has developed its physical habitat simulation models from a variety of other models. Some of the key methods used to develop the habitat portion of IFIM include the Tennant Method (Tennant 1976), the Washington Method (Nickelson 1976, Miller 1976), and the Wetted Perimeter Method (Bartschi 1976). The idea of describing the stream in terms of percentage of the average stream flow instead of actual flow volume is known as the Tennant or Montana Method. The Tennant method defines an instream flow as a fixed percentage of historic average flow at a particular stream site which can be justified to provide protection and habitat for all aquatic resources. This is preferable to setting a predetermined, measured volume of water that may not be available in drought years. Historically, criteria for minimum flows resulted in recommending one all time historical minimum flow. Tennant likened this to prescribing a person's all time worst health condition as the recommended level for a his future well-being.

The Wetted Perimeter Method is another "standard-setting technique, based on an assumed relationship between wetted perimeter and fish habitat in streams. A channel profile is determined for each segment, including velocities, depth, width surface area, and wetted bottom of the stream cross-section that is estimated to minimally protect all habitat needs. Such methods assume that the maintenance of suitable habitat conditions in stream riffles will also provide suitable conditions in pools, as well as allowing migration of fish. Therefore it is common to apply wetted perimeter on riffles rather than in pools. Early methods resulted in a single stream flow value: a minimum flow, recommended for a defined period of time in an individual stream.

The Washington Method was developed to evaluate spawning requirements. It used multiple stream transects to map spawning areas. Several measurements of depth, velocity and substrate were made across each transect and a composite map was constructed showing areas of suitable habitat. By repeating the process for multiple discharges, a minimum flow could be prescribed to protect 75% of the maximum potential spawning habitat.

If a system requires only a single use plan - for instance, your only management prescription is to maintain enough flows to cover spawning beds during winter, and diversions are not a problem, one of the minimum flow methods may well be sufficient.

However, if there are multiple issues and multiple management objectives, these early methods will probably be inadequate as they provide too little information to allow analysis of alternative management practices and informed decision making. The above models are simple and easily applied, but used exclusively, are not sufficient for most applications.

A method was needed that could be used to evaluate the impacts to instream uses resulting from different water management alternatives. Water resource managers were faced with a complex set of problems including maintaining fish habitat in relatively unaltered riverine systems, restoring fish and wildlife habitat in regulated rivers, and meeting increasing recreational and municipal water requirements which were often inconsistent with ecological needs.

Professionals in various disciplines must collaborate to determine how much water there actually is in a specific watershed for a given year; how much water actually gets down through a dynamic changing channel; and which users have the highest priority rights. All of this must be determined within ever-changing political guidelines, public interest pressures, expanding populations, and shifting definitions of what constitute beneficial uses of water.

Project bargaining often depends on in-depth knowledge of flow requirements for fish and wildlife, recreation, water quality, and other instream uses, as well as the ability to integrate these concerns into plans for specific project operations. Water management plans must be supported by quantifiable information and be defensible in a court of law. The means most often used to quantify instream flow needs is to build a case around fish and wildlife habitat, and how habitat changes with varying flow regimes.

The IFIM, while complex and costly, is a state-of-the-art technique which draws on these earlier techniques and more, providing the best available definition of lotic habitat as a function of discharge. As well as modeling changing uses and changing habitat conditions depending on instream flow mitigations, IFIM also provides methods for modeling negotiations involving multiple groups and policies.

It is easier and more cost effective to maintain existing habitat than to rehabilitate it. Therefore it is important that managers take proactive role in long-term habitat protection strategies.

With the enactment of the National Environmental Policy Act (NEPA) and the shift in federal focus toward comparative assessment and management or major federal projects, a more variable, quantitative method of instream flow evaluation was required.

HISTORY OF IFIM

The National Ecology Research Center (NERC) of the U.S. Fish and Wildlife Service is responsible for developing one set of habitat-analysis methods for resource managers to use in various types of stream flow negotiations. The technology that NERC has developed employs a series of computer models to assess the effects of altered stream flow on fish habitat. These are multi-variable models that estimate flow-related changes in physical habitat characteristics such as depth, velocity, substrate, cover, water quality, and water temperature. Changes in these variables are expressed in terms of their effects on available fish habitat at different stream flows.

The Instream Flow Incremental Methodology (IFIM) provides a framework for understanding and developing rules for water storage and release. The first sign of an incremental problem is when conflict arises between a proposed change in the flow regime and the standard set for the stream. An impact to the instream resource is implied by definition when the standard is likely to be violated. The question is how big is the impact and what can be done to alleviate it.

The IFIM has been used over 650 times (Armour and Taylor 1991) to assess the environmental impacts of flow alterations in the nation's rivers. This is a complex and systematic process of assessing, studying and modeling the interactions of many variables (Bovee, 1982). However, because law and science are conceptually different systems, to the amazement of most scientists, even good science may not prevail in court to justify requested minimum flows for fish (Goldfarb 1988). Therefore, it takes a team of professionals ranging from the biologists and engineers to social and political scientists to establish minimum instream flows.

Reservoir operations, hydropeaking, channelization, dredging, and water management networks are "incremental" problems. They are called incremental because of the need to show how changes in the flow regime affect habitat for instream resources.

Incremental methodologies are repeatable processes by which 1) a fishery habitat-stream flow relation and the hydrology of the stream are transformed into a baseline habitat time series, 2) proposed water management alternatives are simulated and compared with the baseline flows, and 3) project operating rules are negotiated. Multiple discharges can be simulated to determine habitat availability at varying stream flows. As an example;

Consider a dam being proposed on the Wanabe River, a degraded fishing stream which also happens to be a highly popular rafting run. Developers are lined up on one side of the room claiming their hydropeaking schedule is critical to the economics of their project. Irrigation companies maintain that they own most of the water in the river through prior appropriation rights. Rafting companies base their livelihoods on the seasonal and diurnal flow regime. Trout fishers are claiming that this project operation would detract from their recreational experience and potentially eliminate industries that they and other recreationists support (fishing gear, licenses, boats, etc.). And fisheries ecologists point out that some rare or endangered fish, that inhabit these waters, would lose their spawning beds if this dam is operated as proposed. It is in situations like this where the IFIM is most useful.

The IFIM can be thought of as tool box. Its many tools can be mixed and matched according to the specific requirements of each stream flow assessment. Complete knowledge of the full kit allows accurate selection of the appropriate tool for each specific task.

The IFIM tool box is organized into four compartments or phases. These are: The Institutional Planning and Problem Identification Phase, the Habitat Simulation Phase, the Assessment of Alternatives Phase and the Negotiation and Resolution Phase.

The Institutional and Problem Identification Phase is really the scoping and study planning process. During scoping, varied values, interests and information emerge which need to be addressed in an organized manner for smooth resolution. The IFIM model provides a procedure for organizing and synthesizing this information which can be a powerful vehicle in negotiating strategies and for reaching final resolution.

During scoping, first, the project location is identified. Second, aquatic organisms and recreational interests that may be affected are determined. Third, management goals and preferences are determined, and forth, project compatibility and management goals are compared. If they are compatible, a finding of no significant impact can be submitted.

If incompatibilities exist, further study is necessary and a study plan should be developed. Development of the study plan should detail the problem. Carefully chosen objectives, the study area, stream segmentation, and evaluation species, and how data collection and analysis will proceed, need to be identified. Early in the planning process there must be agreement on who can make these important decisions.

If the study objectives are not clearly spelled out, two otherwise identical applications of the methodology could result in vastly different conclusions. For example, two groups might agree that the managed flow regime should maintain a fishery at a "minimally acceptable level." To one group this really means, "to maximize fish habitat within the constraints of the available water supply." To the other group, however, minimally acceptable level means, "to maximize out-of-channel water diversion, but without eliminating the fishery." Once the specific objectives are agreed to, the lead organization should delegate responsibilities and establish a reasonable time scale for deliverables. The collection of information then proceeds.

As watershed conditions change, aquatic habitat changes. As habitat changes, the numbers and species inhabiting the stream change. Because habitat is quantifiable, you might assume that increasing habitat provides more fish. As the present state-of-the-art, IFIM does not claim to equate habitat to fish biomass. There are too many other variables that can affect fish populations such that they may or may not fill all the potential habitat (Mathur 1985; Orth & Maugham 1986; Scott and Shirvell 1987; Orth 1987, Behnke 1991). What IFIM does do is provide a vehicle for communication by defining the river in a common quantifiable language in terms of the potential habitat provided by alternative flow regimes.

Simulating the changes in physical habitat that would occur with different flows is perhaps the best known and most utilized component of the IFIM. Components of physical habitat are divided into two categories: macrohabitat and microhabitat.

Macrohabitat includes those characteristics of the environment affecting the longitudinal distribution and abundance of fish species a stream. The physical macrohabitat features of a stream include channel characteristics, discharge, water quality and temperature. These characteristics are relatively constant within a given reach, but vary up and down stream. Several vary with time of year. Before proceeding to more detailed physical features of the stream, baseline hydrology data and benchmark resource data need to be established.

Macrohabitat tools fall into three categories: 1) Temporal variation in stream flow. This affects water supply and is a driving variable for both microhabitat and other macrohabitat variables. 2) Temporal variation in channel structure. Driving variable for microhabitat, and 3) longitudinal suitability as a function of stream flow, time of year, and land use. This includes temperature and water quality.

As habitat changes, the numbers of species inhabiting a stream reach may change. Channel structure and stream flow interact to determine actual living space of the fish species at different lifestages. Water quality and temperature simulation models compute the relation between useable habitat and stream distance from a specified point at different flows at different time of the year, and with different land use patterns or loading rates.

Baseline Hydrology data provides the standard by which the aquatic resource has evolved with. By quantifying streamflow regimes using historical flow record (10 - 20 years), acquiring estimates of flow regime with the proposed water management alternatives in place and 3) comparing these hydrologic series to identify periods of significant differences, the baseline hydrology can be established.

Benchmark resource data establishes the biological, historical information which will be subjected to a proposed change. Once the species of concern has been identified, the seasonal species distribution and abundance must be determined. Only then can you simulate the habitat needs and potential effects of alternative flow regimes of the project.

Microhabitat models calculate the suitable area for an individual life stage of a species, based on variables such as depth, velocity, cover, and substrate. Suitable microhabitat typically varies with discharge similar to this.

Microhabitat tools fall into four categories: 1) channel structure models, 2) hydraulics models, 3) habitat suitability criteria, and 4) microhabitat simulation models. Channel structure models - describe channel properties and dimensions as well as distribution of substrate and cover. Hydraulics models -predict water surface elevations, depths, and velocities at different discharge rates. 3) Habitat suitability criteria rules assign a value to the measured, physical resource parameters specifying their suitability for a specific species and lifestages.

Resource suitability values are combined to yield a composite microhabitat suitability score (Nestler, etal 1989). This composite value is used to "weight" the relative suitability of that habitat for a particular species and lifestage: the best habitat is weighted higher - close to "one", marginal habitat is weighted much lower, close to "zero". The resulting equation is:

Weighted Useable Area (WUA) = Area X Composite Suitability Index

Microhabitat simulation models are variables from the resource categories integrated with streamflows to compute the relation between microhabitat and discharge at specific stream sites.

In IFIM, the output from the macrohabitat components of temperature and water quality is the length of stream having suitable conditions for habitation at a given streamflow. The output from the microhabitat component is the area of stream, per unit length, having suitable microhabitat conditions. These two measures of habitat are then integrated to determine the total habitat area in a complete stream segment.

The IFIM output presents simulations of macrohabitat and microhabitat useable areas. These are integrated to represent the weighted useable area of habitat for a species and specific lifestage.

Projecting weighted useable area over time, with varying flows, produces a summary, the Habitat Time Series. The integrated habitat time series is derived from the numbers of suitable miles times the suitable area per mile for specific flow at a specific time. This is repeated for each time step in the baseline and proposed hydrologic time series.

In the assessment of alternatives, using IFIM, there are four basic concerns which must be addressed: 1) Effectiveness - Does this alternative meet the habitat objectives set forth in the study plan? For instance; no loss of spawning habitat. 2) Feasibility - Is it physically possible to operate the project in this manner? That is - Will this alternative release pattern dry up the reservoir. 3) Risk - How often is this alternative likely to fail? Will there be flooding or bridge failure that increase liability? 4) Economics - Which alternatives achieve the habitat objectives for the least amount of investment, or allow the greatest return to the project developer; a cost/benefit analysis.

Using the IFIM in its entirety is not easy. It is designed for evaluating water management alternatives for projects likely to have significant impact on the aquatic environment. It may be necessary to devote several months and multiple field crews to carry out a complete IFIM study. Even when faced with complex incremental problems, budget restraints and the relative importance of the aquatic system at risk must be considered in deciding whether the IFIM is appropriate, and which component models to use.

The Resolution Phase is the fourth and final component of IFIM. The philosophy of IFIM is to resolve problems though integrative negotiation, using the power of real-time formulation and evaluation of alternatives. The goal is to work together to develop a management alternative that meets the needs of all the parties to the negotiation. This is easier said then done and sometimes a stalemate is reached and the final decision will be accomplished through arbitration by the courts or other decision authorities (Lamb 1992).

In our WANABE RIVER example the IFIM analysis reveals a modified alternative that is acceptable to all parties. With the dam in place recommended alternatives provide for:

a) changing flow regimes for different times of the year to accommodate critical lifestages of selected species, to enhance natural reproduction;

b) sustained flows during spring and summer extend the rafting and kayaking season,

c) a tailwater trophy fishery can be created that didn't exist before,

d) a reservoir bi-level fishery can be created that didn't exist before,

e) the reservoir provides water surface recreation that didn't exist before.

f) agriculture/irrigation companies concur because they can release water from upper reservoirs throughout the year with net storage gain.

g. Negotiated flows with temperature regimes were established to accommodate the endangered fish population by enhancing their spawning and rearing habitat.

Resource managers today face a challenge of restoring the natural aquatic environment under heavy demands for alternative uses of water. Having a tool to assist them in defining objectives, in gathering and analyzing information, in formulating and evaluating alternatives, and in resolving conflicts can help provide decision makers with proactive management choices that can accommodate multiple uses.

Compromise can never optimize conflicting water use priorities. In a few instances, for example where any change in flow might endanger a rare species, no compromise may be possible.

However, in many water allocation negotiations, creative solution can allow protection of both natural and economic resources sufficient to allow viable, collateral system operations. The IFIM is designed to assist water managers in the often unpopular task of prescribing flow recommendations for multiple-uses while maintaining consideration for ecosystem protection.

APPENDIX C

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To: Dr. Stalnaker

OFFICE MEMO

From:

~~TO:~~ T. J. Keefe

Date

FROM: R. J. Behnke, Dept. Fishery & Wildlife Biol.

2

SUBJECT:

REMARKS: Kenny Dinan's final version of plan-B Prof. Pap. and signature page - Please sign and return for Clare Stalnaker's signature.

Thanks from Kenny & me

Then, back to Dr Behnke, I assume.

TJK

UnPublished
[1992]

PROFESSIONAL PAPER

APPLICATION OF THE STREAM NETWORK TEMPERATURE MODEL (SNTEMP) TO THE CENTRAL PLATTE RIVER, NEBRASKA

Submitted by
Kenneth F. Dinan
Department of Fishery and Wildlife Biology

In partial fulfillment of the requirements
for the Degree of Master of Science
Colorado State University
Fort Collins, Colorado
Fall, 1992

ABSTRACT OF PROFESSIONAL PAPER

APPLICATION OF THE STREAM NETWORK TEMPERATURE MODEL (SNTEMP) TO THE CENTRAL PLATTE RIVER, NEBRASKA

Water temperature is thought to be a critical macrohabitat variable affecting the suitability of forage fish habitat in the central Platte River. Water temperature data collected from different locations along the central Platte River during the summers of 1988, 1989, and 1990, were compiled and used to calibrate and validate the Stream Network Temperature model (SNTEMP) for the central Platte River. This calibrated model was used to predict daily mean and maximum water temperatures at different locations throughout the study area. The calibrated SNTEMP model was further used to predict changes in water temperatures as a result of an increase or decrease in discharge. Flows of 11.3, 22.6, and 33.9 cms at the U.S. Geological Survey Grand Island gage were simulated and evaluated to determine how frequently lethal temperatures of forage fishes were exceeded under the three different flow scenarios. Results indicate that by providing adequate flows, the frequency and duration of lethal temperatures for the Platte River fish community can be reduced

throughout the study area and assist in maintaining and protecting an abundant and diverse assemblage of fish species in the central Platte River ecosystem.

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Fort Collins, CO 80523
Fall 1992

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INTRODUCTION

The Stream Network Temperature Model (SNTEMP) was applied to a 129 km (80 mile) reach of the central Platte River, Nebraska. The SNTEMP Model was developed by the U. S. Fish and Wildlife Service's Instream Flow and Aquatic Systems Group (now National Ecology Research Center) in cooperation with the U. S. Soil Conservation Service (Theurer et al. 1984). This model was used to develop an understanding of the relationship between discharge and water temperature for the central Platte River during the summer months under current meteorological, hydrological, and stream geometry conditions.

Objectives of this study included: (1) collect and compile data for and calibrate the SNTEMP model for the central Platte River; (2) use the SNTEMP model to predict mean and maximum daily water temperatures at different locations throughout the central Platte River; (3) use the SNTEMP model to simulate the changes in mean and maximum water temperature that will result from changes in flow; and (4) determine how frequently lethal temperatures for forage fishes were exceeded under three different flow scenarios.

The Platte River in central Nebraska provides important habitat for a variety of fish and wildlife species (Krapa 1981; Currier et al. 1985; USFWS and USBR 1990). Over 50 species of fish have been found in the Platte River system (Johnson 1942;

Morris 1960). The once abundant fish fauna provided a food source for a variety of piscivorous wildlife species. Over 30 species of birds are believed to forage on fish from the Platte River. The endangered interior least tern (_Sterna antillarum_), which was placed on the Endangered Species list on 27 June 1985 (U.S. Fish and Wildlife Service 1985), feeds on fish from the Platte River (Lingle 1988; Wilson 1991) while nesting in the Platte River valley. Interior least terns feed almost entirely on small fish, primarily minnows (Cyprinidae), throughout their entire life (Anderson 1983; Carreker 1985). Wilson (1991) documented that the most frequent fish prey brought back to the nest by interior least terns along the central Platte River included plains killifish (_Fundulus zebrinus_), red shiners (_Cyprinella lutrensis_), creek chub (_Semotilus atriomaculatus_), and other shiner species (_Notropis_). Other species observed included: white suckers (_Catostomus commersoni_), gizzard shad (_Dorosoma cepedianum_), and largemouth bass (_Micropterus salmoides_). Lingle (1988) collected sand shiners (_Notropis stramineus_), red shiners, and river carpsuckers (_Carpiodes carpio_) directly from least terns during banding efforts along the central Platte River and observed least terns feeding on plains killifish.

The quantity and timing of flows needed to provide suitable habitat for the forage fish community in the Platte River has been addressed through numerous assessments of physical habitat (Chadwick and Associates 1989; Biology Work Group 1990; Hardy et al. 1990; U.S. Bureau of Reclamation 1991) using all or parts of the U.S. Fish and Wildlife Service's Instream Flow Incremental Methodology (IFIM) (Bovee 1982). These assessments of the physical habitat of the forage fish community have been based primarily on microhabitat variables such as depth, velocity, substrate and/or cover. A relationship between water temperature and discharge as it relates to habitat suitability has not been incorporated into these habitat assessments. Flows must be adequate to provide both physical fish habitat and sustain adequate water quality (i.e., water temperature) (USFWS and USBOR 1990).

Sensitivity of forage fish to discharge-related changes in water temperature is of primary importance when evaluating impacts of past and future water management projects that alter the amount and timing of flows. Flows which provide habitat for survival and annual production of forage fishes used by least terns must be maintained all year (USFWS and USBOR 1990). Existing and future projects may directly and/or indirectly affect suitability of habitat for fish and wildlife species (e.g., sand shiner, channel catfish, mollusks, interior least terns, and bald eagles), by altering the thermal regime of the river.

Elevated water temperatures affect fish in a variety of ways. Small fish have internal body temperatures that approximate external water temperatures (poikilothermous); thus, profound changes in physiology accompany environmental temperature changes (Lantz 1970; Crawshaw 1979). Matthews and Maness (1979) indicated that fishes of prairie streams in summer are often at temperatures that are near lethal. Fish physiology can be altered during these high water temperature conditions influencing survival rates, growth rates, embryonic development, and susceptibility to parasites and diseases (Fry 1971; Andrews and Stickney 1972; Matthews et al. 1982; Bakanov et al. 1987, Armor 1991).

Elevated water temperatures can also affect metabolism, fluid-electrolyte balance, and the acid-base relationship within fish (Lantz 1970; Islam and Strawn 1975). Fish behavior can also be altered with respect to habitat utilization activities, distribution, and species interactions (Crawshaw 1977; Matthews and Hill 1979; Adams et al. 1982; Stauffer et al. 1984). Changes in water temperature can also affect timing of spawning, duration of incubation, and timing of gonadal maturation (Fry 1971; Matthews and Maness 1979; Armour 1991). Water quality of a stream is influenced by changes in water temperature which affect solubility of dissolved gases, deoxygenation rates and synergistic toxicity (Theurer et al. 1984).

Water temperatures in the central Platte River have exceeded the tolerance level of many forage fish species during summer months (Figure 1) and are believed to be a critical factor in determining both abundance and diversity of forage fishes. Matthews (1986) indicated that brief episodes of high temperature extremes can rapidly raise water temperatures in shallow prairie

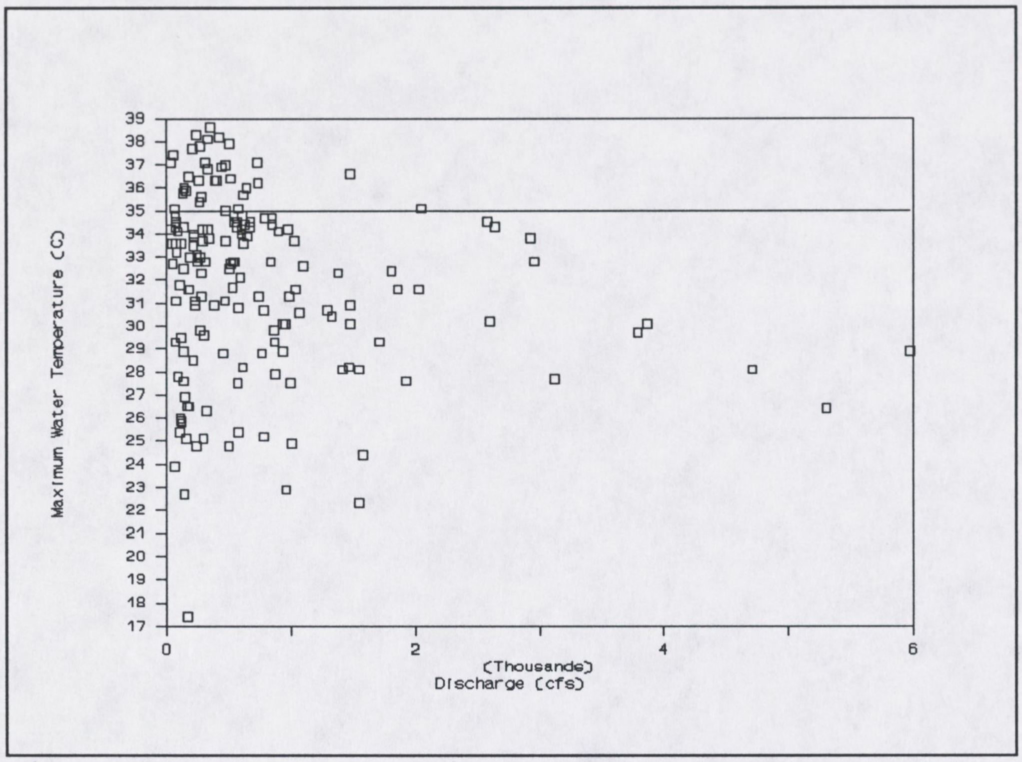

Figure 1. Observed maximum water temperatures (℃) at the Phillips site and a 35℃ reference line versus Platte River discharge (cfs) at the Grand Island gage, during the summers of 1989 and 1990.

streams to ambient air temperatures, creating severe environmental "crunches" for native fishes. Fannin (1988) estimated 44,000 dead fish in the central Platte River as a result of high water temperatures (39.5°C) and low flows. Species found by Fannin during this fish kill included river carpsuckers, common carp (Cyprinus carpio), channel catfish (Ictalurus punctatus), redhorse (Moxostoma spp.), freshwater drum (Aplodinotus grunniens), suckers (Catostomus spp.) and minnows (Cyprinidae). Chadwick and Associates (1990) reported that the number of species in the area of the fish kill, reported by Fannin (1988), was significantly lower than in reaches of the river both upstream and downstream one year after the fish kill. Lingle (1990) reported that fish kills occurred in five out of six summers between 1985 and 1990 on the central Platte River and that adequate instream flows must be protected to satisfy the life requisites of forage fish species.

STUDY AREA

The study area includes a 129 km (80 mile) section of the Big Bend reach of the central Platte River, from Overton to Chapman, Nebraska (Figure 2). The climate in central Nebraska, near Grand Island is primarily continental with occasional incursions of maritime tropical air from the Gulf of Mexico. Summers are usually hot and dry with air temperatures often reaching 38°C (100°F) or greater (National Oceanic and Atmospheric Administration 1989). Average annual air temperature for the Grand Island area is 10°C (50°F) (Cinquemani et al. 1978) while the average annual precipitation is 24.7 inches (National Oceanic and Atmospheric Administration 1989). Topography of the Platte valley is relatively flat with a gradual rise in elevation from Chapman (540 m) to Overton (700 m). Average rise in riverbed from east to west is approximately 2.1 meters (7 ft) per mile (Currier et al. 1985).

Most of the flow of the Platte River is derived from spring runoff that originates as snowmelt in the Rocky Mountains with additional flows from spring precipitation. The Platte River is affected by several major irrigation and hydropower projects with about 70% of average annual flows being diverted before reaching the study area (Williams 1978). Additional water development projects and relicensing of existing hydropower/irrigation

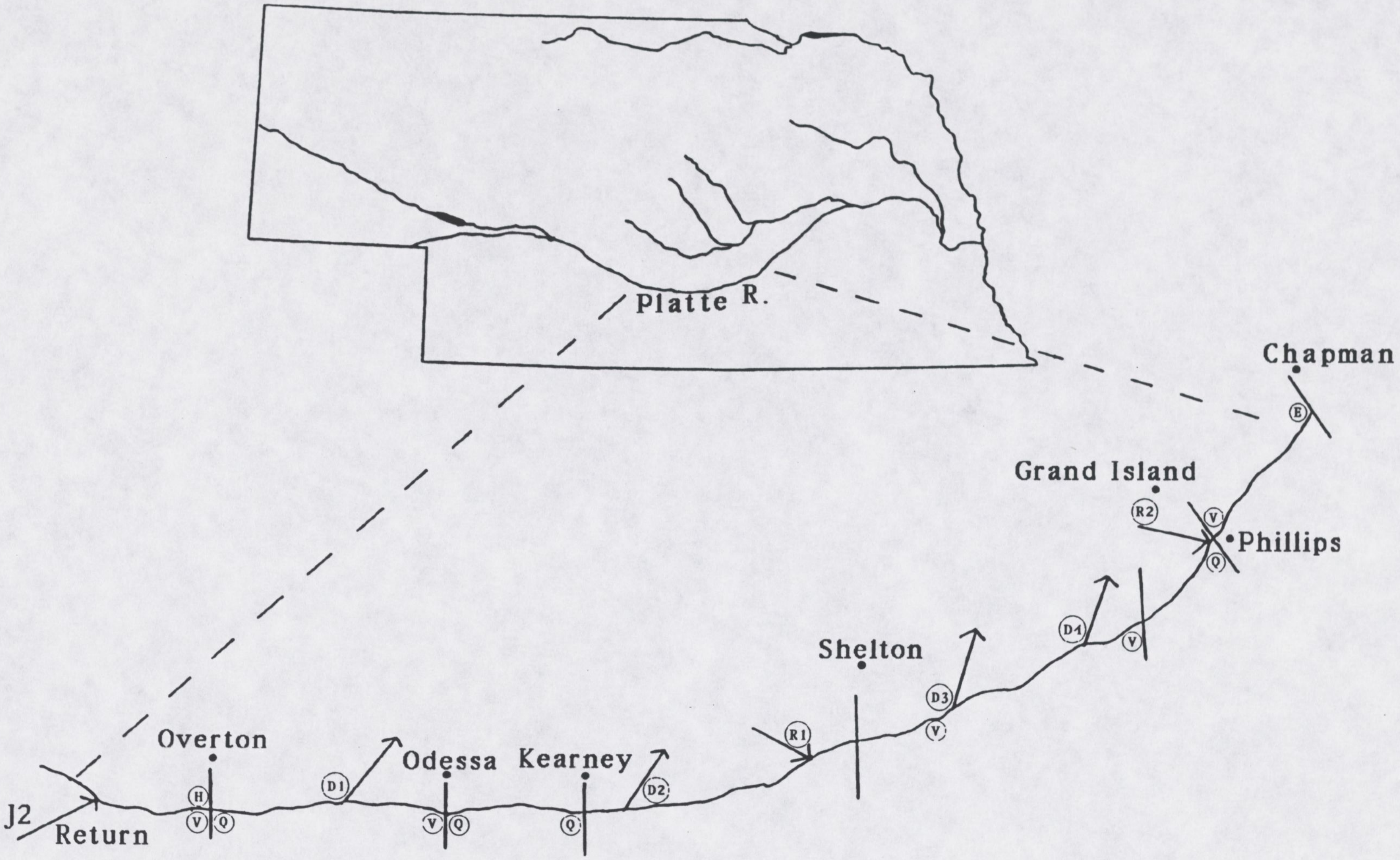

Figure 2. Map of study area within the Big Bend reach of the central Platte River, Nebraska, showing locations of hydrology and validation nodes. (H = upstream boundary, Q = discharge, D = point of diversion, R = point of return, E = downstream boundary, and V = validation (water temperature)).

projects could further alter the timing, magnitude, and duration of flows.

METHODS

For this study, the SNTEMP model was used to analyze the thermal regime of the central Platte River and to evaluate the effect of discharge on water temperatures lethal for forage fish species. The SNTEMP model was developed to predict instream water temperatures based on historical or synthetic hydrological, meteorological, and stream geometry conditions (Theurer et al. 1984). The model was calibrated to the time period 1 June to 31 August, 1989 and 1990. Water temperature data collected during the summer of 1988 was used to test the performance of the model. A daily time step was chosen for the analysis. The SNTEMP model was run on a 386 desktop IBM-compatible computer.

Features incorporated into the model include: (1) a heat transport model that predicts the average daily water temperature and diurnal fluctuations in water temperatures as functions of stream distance; (2) a heat flux model that predicts the energy balance between the water and its surrounding environment; (3) a solar model that predicts the solar radiation that penetrates the water surface as a function of latitude, time of year, and meteorological conditions; (4) a meteorological model that predicts changes in meteorologic variables as functions of a change in elevation; and (5) a regression model that smooths and/or fills in missing water temperature data. (Theurer et al. 1984).

To evaluate the effects of a modified flow regime, flows of 11.3 cms (400 cfs), 22.6 cms (800 cfs), and 33.9 cms (1200 cfs) at the U.S. Geological Survey (USGS) Grand Island gage were simulated. These increments of flow were chosen for simulation because they were in the range of flows most often discussed as providing suitable microhabitat in the river for certain forage fish species. All three flow regimes modeled, in addition to actual flows that occurred during the summer of 1989 and 1990, were evaluated to determine if an increase in flows would decrease the frequency of lethal temperatures occurring in the study area.

The lethal temperature for the forage fish community was assumed to be 35°C for comparison purposes only. Fish show preferences for different temperature ranges as well as having different temperature tolerances. For example, the Critical Thermal Maximum (CTM) reported by Matthews (1987) for the sand shiner and the emerald shiner (<u>Notropis</u> <u>atherinoides</u>) equalled 36.13°C (+/-0.64°C) and 34.47°C (+/- 1.23°C), respectively. The CTM is a measure of thermal tolerance among ectothermic vertebrates and invertebrates. Matthews (1986; 1987) also found the CTM from 18 different populations of red shiners to be within +/- 0.35°C of 36.0°C. Both the red shiner and the sand shiner have been found to have a high thermal tolerance and also a high tolerance for low oxygen levels (Matthews 1987) whereas the emerald shiner has a low thermal tolerance (Matthews 1987; Matthews and Maness 1979).

Data collection techniques described by Bartholow (1989) were used in gathering information and synthesizing the input data. A data base was compiled which included the following: (1) water temperature data, (2) climatological data, (3) hydrological data and (4) stream geometry data. All four categories of data are required by the SNTEMP model. Nodes within the study area that were included in the water temperature model are listed in Table 1. A node is a point in the river where a discontinuity in any of the variables (climatology, hydrology, or stream geometry) occurs.

Water Temperature Data

Historical water temperature data for the central Platte River are limited. A continuous temperature recording device was located at the Overton gage prior to 1975 but had broken down and was not replaced (pers. comm. Engel USGS 1990). Grab samples taken once a day at the Overton site provided the only data available from 1975 until the time of this study. This quality of data was insufficient for modeling the central Platte River thermal regime. However, some of the grab sample data were incorporated if the temperatures were recorded during the time of day which most often reflected the mean daily water temperature (between 10:30 a.m. and 1:30 p.m.)

Table 1. List of nodes within the study area that were incorporated into the water temperature model for the central Platte River.

Stream Name	Node[b]	Distance (km)[a]	Site Description
Platte River	H	128.7	Overton Gage (Seg3)
Platte River	C	115.2	Elm Creek (Seg4A)
Platte River	Q	113.4	Elm Creek
Platte River	D	113.0	Diversion 1 (Kearney canal)
Platte River	C	109.3	Elm Creek (Seg4B)
Platte River	Q	104.4	Odessa Gage
Platte River	V	104.4	Odessa Thermograph
Platte River	C	104.4	Odessa (Seg5)
Platte River	Q	90.2	Kearney Gage
Platte River	D	83.8	Diversion 2 (N Channel/Seg7)
Platte River	C	83.8	Kearney (Seg6)
Platte River	R	65.2	Return 1 (Diversion 1 and 2)
Platte River	C	65.2	Gibbion (Seg8C)
Platte River	C	61.8	Shelton (Seg8A)
Platte River	C	54.5	Shelton (Seg8B)
Platte River	V	51.9	Shelton Thermograph
Platte River	D	50.8	Diversion 3 (N Channel/Seg11)
Platte River	C	50.8	Wood River (Seg9)
Platte River	D	35.3	Diversion 4 (Mid Channel/Seg 10)
Platte River	V	29.8	Mormon Island Thermograph
Platte River	R	16.1	Return 2 (Diversion 3 and 4)
Platte River	C	16.1	Grand Island (Seg12B)
Platte River	Q	15.9	Grand Island Gage
Platte River	V	12.6	Phillips Thermograph
Platte River	C	8.7	Phillips (Seg12A)
Platte River	E	0.0	Chapman bridge

[a] Represents distance upstream from Chapman Bridge.

[b] H = Upstream boundry, C = change in stream geometry, Q = discharge, D = point of diversion (split channels), V = validation (known water temperature, R = point of return, E = downstream boundary

During this study, additional water temperature data were collected from five study sites along the central Platte River (Overton, Odessa, Shelton, Mormon Island, and Phillips). Locations of the thermographs are shown on Figure 2 and listed in Table 1. Two types of water temperature recorders were used (Ryan Model J and Ryan TempMentor thermographs). Ryan Model J thermographs are continuous recorders and are accurate within +/- 0.6°C. The Model J thermographs were provided by the Nebraska Game and Parks Commission. Data from the Model J thermographs were read from the tape at hourly intervals and then averaged over a 24 hour period to determine the daily mean. The daily maximum and minimum were also recorded for additional analysis.

The Ryan TempMentors were programmed to record the water temperature every 10 minutes and are accurate within +/-0.3°C. TempMentors were provided by the U.S. Fish and Wildlife Service's Enhancement office located in Grand Island, Nebraska and the Platte River Whooping Crane Critical Habitat Maintenance Trust. Water temperatures were downloaded according to the procedures described by Ryan Instruments Incorporated (1985). These data were summarized into hourly means, daily means, daily maximums and daily minimums using a program called ReadRyan (Bartholow 1990).

Thermographs were attached to steel cables and anchored to 7-foot steel fence posts that were driven into the river bed. This design allowed the thermograph to float in the river with the sensor completely submerged in water and prevented the sensor from silting in. Thermographs were placed so that even during low flows, thermographs recorded accurate water temperatures. All five thermographs were calibrated with an American Society for Testing and Materials (ASTM) thermometer (which met or exceeded the National Institute Standards and Technology specification for accuracy) before they were placed in the river and after they had been removed from the river. Thermographs were also checked at least once every other week and recorded temperatures were verified with an ASTM thermometer during each site visit.

Missing water temperature measurements at the five thermograph locations were estimated by a standard linear regression algorithm as described by Theurer et al. (1984). Temperatures of return flows were assumed to be at thermal equilibrium. Ground water temperature during the summers of 1988, 1989, and 1990 were determined from shallow wells along the Platte River near Elm Creek, Kearney, and Grand Island, Nebraska and averaged 15.2°C (59°F) (Wyoming Water Research Center unpublished data).

Climatological Data

Mean and maximum daily air temperature, wind speed, percent possible sunshine, solar radiation and relative humidity were the primary climatological variables. Most of this information was available from the Local Climatological Data (LCD) monthly summary reports for the Grand Island National Weather Service

Office located approximately 8.8 km (5.5 miles) north of the Platte River (National Climatic Data Center, periodic).

Some of the information that was available on the LCD's was not in the form required by SNTEMP and thus had to be converted (e.g. relative humidity and percent possible sunshine). Appendix A (Tables A1, A2, and A3) contain the meteorological data for each daily time period used during the analysis. Relative humidity was determined from Equation 1 (Linsley et al. 1975) and was then multiplied by 1.2 to account for differences between the relative humidity near the river (Wyoming Water Research Center unpublished data) and that measured at the Grand Island weather station.

Equation 1. $$Rh = [(112 - 0.1\,(TA + Tdp))/\ 112 + 0.9\,TA]^{8}$$

where: Rh = relative humidity

TA = temperature of the air (°C) (dry bulb)

Tdp = dew point temperature (°C)

Percent possible sunshine (PPS) was determined from the values for sky cover in the LCD reports using Equation 2 (Theurer et al. 1984).

Equation 2. $$PPS = 1-Cl^{5/3}$$

where: Cl = cloud cover (decimal)

PPS = percent possible sunshine

Solar radiation was estimated using the SNTEMP program which estimates daily solar radiation for a certain time of year and set of conditions. Twenty percent was used to represent ground reflectivity. Ground reflectivity is the percent of shortwave radiation reflected from the earth into the atmosphere. This is an average of various homogeneous ground cover conditions such as meadows, fields, and grass covered flat ground (Bartholow 1989).

The dust coefficient for Lincoln, Nebraska during the summer months was reported by the Tennessee Valley Authority (1972) as 0.03 and 0.04. The dust coefficient supplied to the SNTEMP model for this study was 0.035. The dust coefficient is an index to the scattering effect that dust and other small particles have on incoming solar radiation.

As recommended by Theurer et al. (1984) and Bartholow (1989), regression coefficients were included to improve the capability of the model to predict maximum daily water temperatures. The coefficients can be found in the job control file (Appendix B) which is the master file that controls the extent of the temperature model runs. These coefficients were determined using Equation 3 (Theurer et al. 1984) and then calibrated to account for differences between the observed and predicted maximum water temperatures at all validation nodes. A validation node is where the water temperature is known and can be compared to the predicted water temperature.

Equation 3. $$T(diff) = T(m) + [a0 + a1(SR) + a2(Rh) + a3(PPS)]$$

where: T(diff) = T(max) - T(m)

T(max) = daily maximum air temperature (°C)

T(m) = daily mean air temperature (°C)

SR = solar radiation (J/m2/sec)

Rh = relative humidity

PPS = percent possible sunshine

a0 through a3 = regression coefficients

Hydrological Data

The primary hydrological variable is discharge. Discharge data were collected from four USGS gaging stations located within the study area (Overton, Odessa, Kearney, and Grand Island) (Figure 2). Discharge measurements recorded at the gaging stations represented mean daily flows. In addition to discharge information provided for the gaging stations, information needed to be supplied at other hydrology nodes within the study area (Table 1). A hydrology node is a point in the river where a discontinuity in hydrology occurs (e.g., diversions, returns, and split channels). The amount of water diverted from the river by the Kearney Canal Diversion and returned to the river by the Kearney Canal Return were obtained from the State of Nebraska Department of Water Resources annual hydrologic reports (1988, 1989, and 1990). All equations used to determine flows at split channels were developed using unpublished data provided by the U.S. Bureau of Reclamation and USGS gage data (USGS 1988,1989, and 1990). Discharge relationships for all hydrology nodes can be found in Table 2. Actual mean daily discharge at the Grand Island gage and those simulated are plotted in Appendix C (Figure C1-C3).

For the simulated flows of 11.3 cms (400 cfs), 22.6 cms (800 cfs), and 33.9 cms (1200 cfs) at the USGS Grand Island gage, the discharge at each gaging station was determined using the USGS flow data for the summers of 1988, 1989, and 1990. A regression analysis was conducted by month to determine the flow relationship between each gage (Overton, Odessa, Kearney, and Grand Island). Flows for all other hydrology nodes within the stream network (e.g., diversions, returns, and split channels) were determined using the discharge relationships described in Table 2.

Stream Geometry Data

The stream geometry data consisted of distances upstream from the lower boundary of the study area (i.e., Chapman), elevations, hydraulic retardence and the stream width versus discharge relationship for each stream geometry node within the study boundary. A stream geometry node is a point in the river where a discontinuity in any of the stream geometry variables takes place (e.g. a change in the relationship between discharge and the wetted width of the stream). Table 3 contains the stream geometry data incorporated in the water temperature model.

Distances upstream from the Chapman bridge and latitudes were determined from USGS 7.5 minute topographic maps. Stream

Table 2. Discharge relationships for all hydrology nodes in the study area.

Site Description	Node	Discharge Relationships and (Sources of Information)
Overton Gage (Seg3)	H	Overton gage (USGS)[a]
Elm Creek	Q	Overton gage or Kearney canal + 1cfs (which ever value is greater)
Diversion 1 (Kearney canal)	D	Kearney canal diversion (NDWR)[b]
Odessa Gage	Q	Odessa gage (USGS)
Kearney Gage	Q	Kearney gage (USGS)
Diversion 2 (N Channel/Seg 7)	D	32% of Kearney gage (BOR)[c]
Return 1 (Diversion 1 and 2)	R	32% of Kearney gage + Kearney canal return (NDWR)
Shelton Thermograph	V	Grand Island gage (USGS)
Diversion 3 (N Channel/Seg11)	D	Grand Island gage - Mormon Island - Diversion 4 (BOR)
Diversion 4 (Mid Channel/Seg10)	D	-4.4641 + (.137069 * Grand Island gage) (BOR)
Mormon Island Thermograph	V	When Grand Island gage < 2000 cfs: -69.1159 + (.480710 * Grand Island gage) or When Grand Island gage > 2000 cfs: -269.506 + (.563958 * Grand Island gage) (BOR)
Return 2 (Diversions 3 and 4)	R	Diversion 3 + Diversion 4
Grand Island Gage	Q	Grand Island gage (USGS)
Phillips Thermograph	V	Grand Island gage (USGS)
Chapman Bridge	E	Grand Island Gage (USGS)

[a] U.S. Geological Survey (1988; 1989; and 1990).
[b] State of Nebraska Department of Water Resources (1988; 1989; and 1990).
[c] U.S. Bureau of Reclamation (1987) and unpublished data.

Table 3. Stream geometry data for all stream geometry nodes in the central Platte River water temperature model study area.

Site Description	Node	Distance (km)	Site Latitude (radians)	Site Elevation (m)	Manning's n	Stream Width Constant	Stream Width Exponent
Overton Gage (Seg3)	H	128.7	0.70991	701.7	0.050	71.960	0.31781
Elm Creek (Seg4A)	C	115.2	0.70992	684.3	0.050	68.837	0.24168
Elm Creek (Seg4B)	C	109.3	0.70992	678.2	0.050	82.174	0.22451
Odessa (Seg5)	C	104.4	0.70963	669.6	0.050	71.960	0.31783
Kearney (Seg6)	C	83.8	0.70963	644.7	0.045	94.362	0.30520
Gibbion(Seg8C)	C	65.2	0.71022	621.8	0.045	101.278	0.22543
Shelton (Seg8A)	C	61.8	0.71051	613.3	0.045	117.428	0.16100
Shelton (Seg8B)	C	54.5	0.71065	605.0	0.045	110.441	0.22355
Wood River (Seg9)	C	50.8	0.71080	598.9	0.020	115.501	0.18723
Grand Island (Seg12B)	C	16.1	0.71312	559.3	0.020	96.069	0.29527
Phillips (Seg12A)	C	8.7	0.71400	551.7	0.020	233.729	0.14038
Chapman bridge	E	0.0	0.71501	538.0			

distances are important in calculation of heat transport (Bartholow 1989). Elevations were also determined from topographic maps. Elevations are used by the model to determine slope, atmospheric pressure, depth of the atmosphere through which solar radiation must pass, and to adjust some of the meteorological variables.

The hydraulic retardence is a measure of the roughness of the streambed and channel causing flowing water to slow down due to friction. The hydraulic retardence or Manning's "n" is a necessary component of the SNTEMP model in predicting daily maximum water temperatures (Bartholow 1989). The values used for Manning's "n" ranged from 0.05 near Overton to 0.02 at Chapman (Table 3).

The relationship between wetted width of the stream and discharge can be a very sensitive parameter when modeling the mean and maximum water temperature. The wetted width as a function of discharge was determined using the procedures described by Bartholow (1989) and Equation 4. Data used to develop this relationship were obtained from the U. S. Bureau of Reclamation (1987).

Equation 4: $W = a\ Q^b$

where W = wetted width

Q = discharge

a and b = empirically derived coefficients

Regression coefficients for each stream geometry node can be found in Table 3 as the "stream width constant" and the "stream width exponent" respectively. The wetted width versus flow relationships for each stream geometry node and the regression statistics can be found in Appendix D (Figures D1-D10).

ASSUMPTIONS AND LIMITATIONS

An assumption inherent within the SNTEMP model is that the hydrology at a single location (node) within the stream network is steady during a 24 hour time period. Fluctuations in flow during a 24 hour period in the summer at the Grand Island gage are usually small. However, large changes in flow can occur as a result of localized precipitation events or by altering the releases out of the Johnson #2 (J-2) return located upstream of the Overton Bridge (Figure 2). Even though the model assumes steady flows at each node, the model does allow for discharges to vary linearly between nodes (Theurer et al. 1984). The SNTEMP model is not a hydrology model; therefore, discontinuity in flow must be provided. Differences in flow between hydrology nodes is assumed to be lateral flow.

An additional assumption of the model is that there is no lateral or vertical distribution of water temperatures at any given location (Theurer et al. 1984). The model assumes that the water temperatures are constant throughout a given cross section at any given instant and that there is homogenous and instantaneous mixing of flows at all returns including lateral flow. However, a longitudinal change in water temperatures is expected and predicted using the SNTEMP model. Based on field observation during the summers of 1988, 1989, and 1990, this assumption is valid for flowing water within the study area. However, isolated pools and rivulets of water which are connected at the downstream end but disconnected at the upstream end may be hotter or cooler than the flowing water, partially due to cool groundwater seeps. During prolonged periods of low flow which frequently occurred during the summers of 1988, 1989, and 1990, these pools and rivulets of water tended to heat-up and/or dry-up causing the fish that were located in these areas to die from water temperatures in excess of their lethal limits or from stranding.

RESULTS

Model Calibration and Verification

Several runs or iterations were made, using the data collected during the summers of 1989 and 1990, to calibrate or better fit the model predictions with the observed data at all validation nodes. Adjustments were made to some of the model's input variables so that the model produced accurate water temperatures at the five validation nodes where known water temperatures existed. No adjustment was made that did not reduce the mean error of the model and increase the correlation coefficient (R) between the model's prediction and the observed water temperature at each validation node.

To calibrate the predicted to the observed mean daily water temperature the relative humidity was multiplied by 1.2. This adjustment was justified based on the difference in relative humidity observed at the river (Wyoming Water Research Center unpublished data) versus that recorded at the Grand Island weather station. This approach is also consistent with Bartholow (1989). Additional adjustments were made to the groundwater temperature. Initial runs included the mean annual air temperature to represent groundwater temperature. Information on groundwater temperatures from wells along the central Platte

River within the study boundary were available and incorporated into the final model.

Calibration of the model increases the accuracy and precision of model predictions at all validation nodes within the stream network. Regression statistics for the final calibration of the model for mean water temperatures are presented in Table 4. The mean error for all validation nodes equaled +0.16°C. That is, on average, the model overpredicted mean water temperatures by 0.16°C. The probable error for all validation nodes equalled +/- 0.82°C indicating that 50% of the model predictions were within 0.82°C of the observed water temperature. Observed and predicted daily mean water temperatures for each validation node are plotted in Appendix E (Figures E1-E10).

Differences between the observed and the predicted maximum water temperatures warranted further calibration. Additional runs were made to align the predicted maximum water temperature with the observed maximum water temperature at all validation nodes (including Overton). Regression coefficients were determined using local meteorological data from the Grand Island weather station. These coefficients were incorporated into the model and improved the model's capability to predict maximum daily water temperatures. Additional adjustments were made to the roughness coefficients (Manning's n). Statistics for the final calibration run for daily maximum water temperature at each validation node are presented in Table 5. There was close enough agreement between the means and standard deviations at each

Table 4. Validation statistics for mean water temperature after final calibration.

Site Description	Node	Distance (km)	Detr. Coef. (D)	Corr. Coef. (R)	Mean Error (C)	Prob. Error (+-C)	Max. Error (C)	Error Terms
Odessa Thermograph	V	104.4	0.8596	0.8688	-0.52	1.00	-6.91	184
Shelton Thermograph	V	51.9	0.9150	0.9322	0.39	0.73	3.38	184
Mormon Island Thermograph	V	29.8	0.9428	0.9601	0.14	0.61	-2.56	184
Phillips Thermograph	V	12.6	0.9412	0.9471	0.63	0.67	3.45	184
All Validation Nodes			0.9048	0.9219	0.16	0.82	-6.91	736

Table 5. Statistics for observed and predicted maximum water temperatures (°C) for all valadation nodes after final calibration.

	Thermograph/Site Description									
Maximum Water Temperature Statistics	Overton		Odessa		Shelton		Mormon Island		Phillips	
	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
Mean	27.50	27.75	29.22	29.72	30.01	30.48	32.84	32.55	31.80	31.50
Maximum	32.80	33.08	37.00	37.59	37.20	38.37	37.50	38.89	38.60	38.76
Minimum	21.40	21.83	17.40	19.68	17.50	20.33	23.50	23.36	17.40	20.73
Standard Deviation	2.727	2.484	3.515	3.768	3.602	3.697	3.236	3.050	3.925	3.620
Mean Error	.81		1.58		1.37		1.25		1.48	
Number of terms	97		145		124		64		163	
R-square	0.8530		0.7434		0.8069		0.7348		0.7742	

validation node not to warrant further calibration. Observed and predicted daily maximum water temperatures for each validation node are plotted in Appendix F (Figures F1-F10). The relationship between predicted and observed maximum water temperature for each validation node are plotted in Appendix G (Figures G1-G5). R-squares ranged from 0.74 at Mormon Island to 0.85 at Overton.

Validation using 1988 Data

To test the performance of the model calibrated to 1989 and 1990 conditions, the calibrated model was used to predict mean and maximum water temperatures for the summer of 1988. Limited water temperature data had been collected at two (Odessa and Mormon Island) of the five validation sites during the summer of 1988. Comparisons between predicted temperatures and those observed at the Odessa and Mormon Island thermographs for both daily mean and maximum water temperatures were conducted to further validate the calibrated model.

All the data used in this simulation were collected and compiled using the procedures described in this document. Climatological data used for this simulation are presented in Appendix A (Table A1). Statistics for the 1988 data set for observed and predicted daily mean and maximum water temperature at each of the two thermographs are presented in Table 6 and 7. There was close enough agreement between the means and standard

Table 6. Observed and predicted mean water temperatures (°C) for the Odessa and Mormon Island thermograph for the summer of 1988.

Mean Water Temperature Statistics	Odessa Thermograph		Mormon Island Thermograph	
	Observed	Predicted	Observed	Predicted
Mean	22.78	21.35	25.93	27.07
Maximum	24.96	25.30	29.38	31.00
Minimum	19.46	17.23	19.00	22.00
Standard Deviation	1.95	2.26	2.58	2.36
Mean Error	1.53		1.34	
Number	20		43	

Table 7. Observed and predicted maximum water temperatures (°C) for the Odessa and Mormon Island thermograph for the summer of 1988.

Maximum Water Temperature Statistics	Odessa Thermograph		Mormon Island Thermograph	
	Observed	Predicted	Observed	Predicted
Mean	27.78	28.77	32.90	33.58
Maximum	30.50	32.09	39.50	38.44
Minimum	23.50	25.42	24.70	27.49
Standard Deviation	2.16	1.83	3.30	2.40
Mean Error	1.55		1.47	
Number	20		43	

deviations at both the Odessa and Mormon Island site to support the use of the calibrated model for the central Platte River. Observed and predicted daily mean and maximum water temperature for both the Odessa and Mormon Island thermographs are plotted in Appendix H (Figure H1-H4).

Results from 1989 and 1990 Simulation

After the model had been calibrated and validated using 1988 data, the results from the 1989 and 1990 simulation were evaluated and compared to three alternative flow scenarios (11.3, 22.6, and 33.9 cms). Results from the 1989 and 1990 simulation indicate that the average daily mean water temperatures increased from upstream to downstream and ranged from 22.82 °C at Overton to 25.32 °C at Phillips (Table 8). Daily maximum water temperatures also tended to increase from upstream to downstream. However, on an average the daily maximum water temperature at the Phillips site was slightly cooler than at the Mormon Island site (Table 9). The highest daily maximum water temperature simulated at the Overton, Odessa, Shelton, Mormon Island, and Phillips site equalled 34.42, 37.59, 38.37, 38.89, and 38.76°C respectively (Table 9). The mean daily maximum water temperature equalled 27.55, 29.94, 30.63, 31.68, and 31.47°C respectively (Table 9).

Daily maximum water temperature predictions for the summers of 1989 and 1990 exceeded 35°C on numerous occasions. Temperatures in excess of 35°C did not occur at the Overton site

Table 8. Simulated daily mean water temperature (°C) statistics for all validation nodes from the 1989 and 1990 simulation.

Mean Water Temperature Statistics	Thermograph Locations				
	Overton	Odessa	Shelton	Mormon Island	Phillips
Mean	22.82	23.19	24.88	25.25	25.32
Maximum	29.00	29.32	32.08	32.12	32.15
Minimum	17.51	14.85	14.97	15.04	15.09

Table 9. Simulated daily maximum water temperature (°C) statistics for all validation nodes from the 1989 and 1990 simulation.

Maximum Water Temperature Statistics	Thermograph Locations				
	Overton	Odessa	Shelton	Mormon Island	Phillips
Mean	27.55	29.94	30.63	31.68	31.47
Maximum	34.42	37.59	38.37	38.89	38.76
Minimum	21.08	19.68	20.33	20.84	20.73
Number of Days Maximum > 35°C =	0	9	11	27	23
Percentage of Days Maximum > 35°C =	0	4.9	5.9	14.6	12.5

but did occur at Odessa 4.9%, Shelton 5.9%, Mormon Island 14.6%, and Phillips 12.5% of the time (Table 9).

Results from Simulation with 11.3 cms (400 cfs) at Grand Island

Simulated daily mean and maximum water temperature statistics for all validation nodes with a flow of 11.3 cms at the Grand Island gage are presented in Tables 10-11. In most cases a flow of 11.3 cms did not provide additional protection to the Platte River fish community from lethal temperatures during the summer months when compared to actual 1989/1990 flow conditions. The highest daily maximum water temperature per validation node decreased as a result of a flow of 11.3 cms. However, this reduction in maximum water temperatures tended to decrease from upstream to downstream with a reduction at Mormon Island of only 0.02°C when compared to the flow conditions that occurred during 1989 and 1990. The mean daily maximum water temperatures increased at all validation nodes except at the Odessa site.

Simulated temperatures in excess of 35°C did not occur at the Overton site with a flow of 11.3 cms at Grand Island, but did occur at Odessa 5.4%, Shelton 8.7%, Mormon Island 17.9%, and Phillips 14.7% of the time (Table 11). This increase in the frequency of temperatures in excess of 35°C when compared to actual 1989 and 1990 flow conditions is a result of reducing the flows to 11.3 cms during high flow periods. This indicates that during the summers of 1989 and 1990 there would have been more

Table 10. Simulated daily mean water temperature (°C) statistics for all validation nodes with a flow of 11.3 cms (400 cfs) at the Grand Island gage.

Mean Water Temperature Statistics	Thermograph Locations Overton	Odessa	Shelton	Mormon Island	Phillips
Mean	22.91	22.75	25.16	25.29	25.32
Maximum	27.10	30.25	32.08	32.12	32.15
Minimum	17.59	14.64	14.97	15.05	15.08

Table 11. Simulated daily maximum water temperature (°C) statistics for all validation nodes with a flow of 11.3 cms (400 cfs) at the Grand Island gage.

Maximum Water Temperature Statistics	Thermograph Locations Overton	Odessa	Shelton	Mormon Island	Phillips
Mean	27.82	29.85	31.00	31.87	31.60
Maximum	32.49	36.92	38.21	38.87	38.69
Minimum	21.13	19.64	19.64	20.77	20.34
Number of Days Maximum > 35°C =	0	10	16	33	27
Percentage of Days Maximum > 35°C =	0	5.4	8.7	17.9	14.7

days where conditions would have been stressful if not lethal to the Platte River fish community with a flow of 11.3 cms at the Grand Island gage, under identical climatological conditions.

Results from Simulation with 22.6 cms (800 cfs) at Grand Island

Simulated daily mean and maximum water temperature for all validation nodes with a flow of 22.6 cms at the Grand Island gage are presented in Tables 12-13. A flow of 22.6 cms did provide additional protection to the Platte River fish community from lethal temperatures during the summer months compared to both the actual 1989/1990 flow conditions and 11.4 cms flow scenario. The mean and maximum daily maximum water temperatures decreased at all validation nodes with a flow of 22.6 cms at the Grand Island gage when compared to 1989/1990 flows and 11.4 cms flow scenario.

Temperatures in excess of 35°C did not occur at the Overton site with a flow of 22.6 cms at Grand Island, while they occurred at Odessa 2.7%, Shelton 5.4%, Mormon Island 14.7%, and Phillips 12.0% of the time (Table 13). The frequency of water temperatures in excess of 35°C was reduced by 50%, 38%, 18% and 18% at Odessa, Shelton, Mormon Island, and the Phillips site respectively, when compared to a flow of 11.3 cms. The decrease in the frequency of temperatures in excess of 35°C is a result of increasing the flows to 22.6 cms during low flow periods. This indicates that during the summers of 1989 and 1990 there would have been fewer days where water temperature conditions would have been stressful if not lethal to the Platte River fish

Table 12. Simulated daily mean water temperature (°C) statistics for all validation nodes with a flow of 22.6 cms (800 cfs) at the Grand Island gage.

Mean Water Temperature Statistics	Thermograph Locations				
	Overton	Odessa	Shelton	Mormon Island	Phillips
Mean	22.79	23.47	25.16	25.30	25.32
Maximum	26.97	30.09	32.08	32.13	32.15
Minimum	17.47	14.88	14.96	15.05	15.08

Table 13. Simulated daily maximum water temperature (°C) statistics for all validation nodes with a flow of 22.6 cms (800 cfs) at the Grand Island gage.

Maximum Water Temperature Statistics	Thermograph Locations				
	Overton	Odessa	Shelton	Mormon Island	Phillips
Mean	26.94	29.13	30.36	31.66	31.24
Maximum	31.73	36.35	37.61	38.73	38.38
Minimum	20.58	19.06	19.09	20.41	19.95
Number of Days Maximum > 35°C =	0	5	10	27	22
Percentage of Days Maximum > 35°C =	0	2.7	5.4	14.7	12.0

community if flows were 22.6 cms at the Grand Island gage, under identical climatological conditions.

Results from Simulation with 33.9 cms (1200 cfs) at Grand Island

Simulated daily mean and maximum water temperature statistics for all validation nodes with a flow of 33.9 cms at the Grand Island gage are presented in Tables 14-15. A flow of 33.9 cms did provide additional protection to the Platte River fish community from lethal temperatures during the summer months as compared to previous flow scenarios of 11.3 and 22.6 cms. The mean daily maximum water temperatures decreased at all validation nodes while the maximum daily maximum water temperature decreased at all validation nodes except Odessa with a flow of 33.9 cms at the Grand Island gage.

Daily maximum water temperatures in excess of 35°C did not occur at the Overton site with a flow of 33.9 cms at the Grand Island gage, but did occur at Odessa 1.6%, Shelton 4.9%, Mormon Island 13.6%, and Phillips 8.7% of the time (Table 15). The frequency of water temperatures in excess of 35°C during this simulation was reduced by 70%, 44%, 24% and 41% at Odessa, Shelton, Mormon Island, and Phillips site respectively, when compared to a flow of 11.3 cms and by 40%, 10%, 7%, 27% when compared to a flow of 22.6 cms. The decrease in the frequency of daily maximum water temperatures in excess of 35°C during this simulation indicates that during the summers of 1989 and 1990 there would have potentially been fewer days where water

Table 14. Simulated daily mean water temperature (°C) statistics for all validation nodes with a flow of 33.9 cms (1200 cfs) at the Grand Island gage.

Mean Water Temperature Statistics	Thermograph Locations				
	Overton	Odessa	Shelton	Mormon Island	Phillips
Mean	22.65	23.74	25.13	25.30	25.32
Maximum	26.85	31.06	31.93	32.13	32.15
Minimum	17.34	15.15	14.96	15.05	15.08

Table 15. Simulated daily maximum water temperature (°C) statistics for all validation nodes with a flow of 33.9 cms (1200 cfs) at the Grand Island gage.

Maximum Water Temperature Statistics	Thermograph Locations				
	Overton	Odessa	Shelton	Mormon Island	Phillips
Mean	26.36	28.68	29.92	31.43	30.95
Maximum	31.21	36.51	37.09	38.54	38.11
Minimum	20.22	18.84	18.69	20.12	19.67
Number of Days Maximum > 35°C =	0	3	9	25	16
Percentage of Days Maximum > 35°C =	0	1.6	4.9	13.6	8.7

temperature conditions would have been stressful if not lethal to the Platte River fish community under identical climatological conditions when compared to previous flow scenarios.

DISCUSSION

Water temperature is thought to be a critical macrohabitat variable affecting the suitability of forage fish habitat in the central Platte River (Fannin and Nelson 1986, USFWS and USBOR 1990). Elevated water temperatures can have a dramatic impact on the overall health of the Platte River fishery which in turn may impact listed species such as the endangered bald eagle and interior least tern. Low flows in combination with changes in physical, chemical or biological factors, can create poor water quality conditions impacting fish populations.

Water temperature data collected from five locations along the central Platte River during the summer of 1988, 1989, and 1990, were compiled and used to calibrate and validate the SNTEMP model for the central Platte River. Data that were incorporated in to this model that improved the overall predictability of the model included: (1) coefficients for the wetted width versus discharge relationship for each stream geometry node in the study area, (2) regression coefficients to improve the models capability to predict maximum daily water temperatures, and (3) actual ground water temperatures from the study area. This calibrated model was used to predict daily mean and maximum water temperatures at different locations throughout the central Platte River. Results from the calibration and validation phase of this study indicate that the SNTEMP model can be used to predict both mean and maximum water temperatures for warmwater streams such as the central Platte River.

The calibrated SNTEMP model was further used to predict changes in water temperatures as a result of an increase or decrease in discharge for the central Platte River. Results from this study indicate that there is a relationship between daily maximum water temperature and discharge throughout the study area. As flow increases, the wetted width and water depth increase. Hence, heat supplied to the water surface by the sun or by warm air is absorbed by a larger volume of water which accordingly results in a lower maximum water temperature (Figure 1) and less fluctuation around the mean (Figure 3).

Results from this study also indicate that increased flows of sufficient quantity during summer months can reduce the frequency and duration of daily maximum water temperatures in excess of 35°C throughout the study area (Figure 4). Flows of 11.3 cms (400 cfs) at the Grand Island gage provided little or no additional protection to the central Platte River fish community when compared to the actual 1989 and 1990 flow conditions. A flow of 22.6 cms (800 cfs) at the Grand Island gage reduced the average daily maximum water temperatures at all validation nodes. In addition, a flow of 22.6 cms reduced the number of days when temperatures were in excess of 35°C at each validation node by an average of 31 percent when compared to the 11.3 cms flow scenario. The percent reduction in the number of days in excess

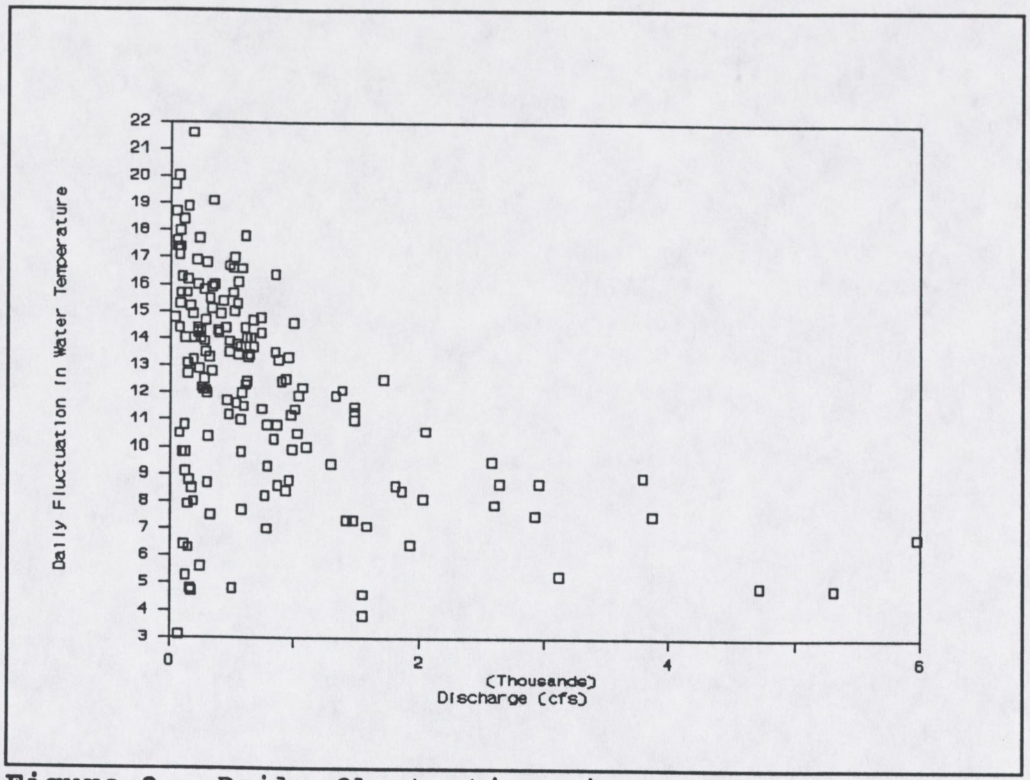

Figure 3. Daily fluctuations in water temperature (maximum - minimum) (ºC) at the Phillips thermograph versus Platte River discharge (cfs) at the Grand Island gage during the summers of 1989 and 1990.

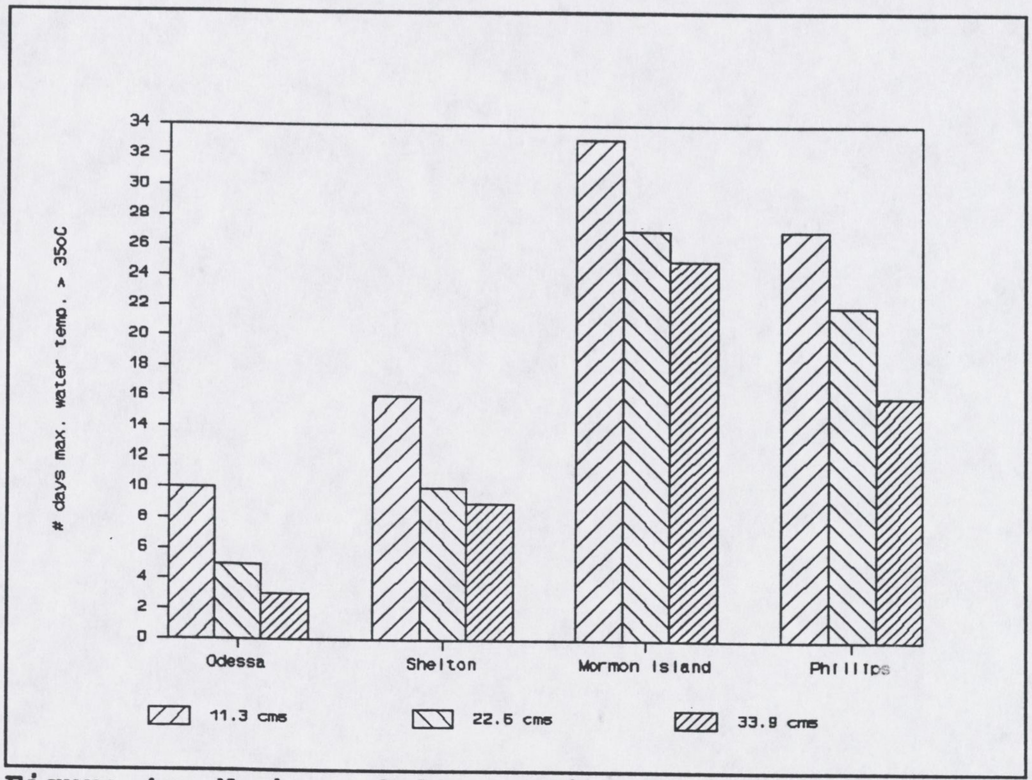

Figure 4. Number of days maximum water temperatures were greater than 35ºC for four locations within the central Platte River under three different flow scenarios.

of 35°C ranged from 50 percent at Odessa to 18 percent at both the Mormon Island and Phillips sites. A flow of 33.9 cms further reduced the average daily maximum water temperature at all validation nodes and reduced the number of days when maximum water temperatures were in excess of 35°C at each validation node by an average of 45 percent. The percent reduction in the number of days in excess of 35°C ranged from 70 percent at Odessa to 24 percent at the Mormon Island site.

Any assessment of impacts of past and future projects (which will alter the amount or timing of flow passing the Grand Island gage) on the suitability of forage fish habitat in the central Platte River should take into account this relationship between water temperature and discharge. Results of this study indicate that to reduce the frequency and duration of potential lethal maximum water temperatures, flows of sufficient quantity must be provided. Results also indicate that reductions in flow during the summer months could increase both the frequency and duration of high water temperatures that adversely impact fish populations. By providing adequate flows, the frequency and duration of lethal temperatures for the Platte River fish community can be reduced throughout the central Platte River and assist in maintaining and protecting an abundant and diverse assemblage of fish species in the central Platte River ecosystem.

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APPENDICES

APPENDIX A

METEOROLOGICAL DATA BY DAILY TIME PERIOD FOR THE CENTRAL PLATTE RIVER WATER TEMPERATURE MODEL (SUMMER OF 1988, 1989, AND 1990).

Table A1. Meteorological data for the summer of 1988 by daily time period.

Time Periods	Mean Air Temperature (°C)	Mean Wind Speed (m/sec)	Relative Humidity (decimal)	Percent Sunshine (decimal)
JUN 1	18.33	4.2	0.97	0.16
JUN 2	18.89	4.6	0.90	0.63
JUN 3	22.78	3.3	0.79	0.82
JUN 4	23.33	3.7	0.79	0.97
JUN 5	21.67	6.0	0.52	1.00
JUN 6	22.78	6.4	0.53	0.99
JUN 7	27.78	5.0	0.54	0.90
JUN 8	25.00	4.3	0.71	0.99
JUN 9	21.67	4.5	0.68	0.82
JUN 10	20.56	5.6	0.38	0.38
JUN 11	25.00	8.2	0.41	0.16
JUN 12	26.67	7.5	0.43	0.44
JUN 13	28.33	7.1	0.47	0.73
JUN 14	22.78	3.8	0.66	0.73
JUN 15	21.11	3.6	0.59	0.51
JUN 16	22.78	4.9	0.57	0.95
JUN 17	25.00	6.2	0.69	0.78
JUN 18	28.89	6.0	0.59	0.57
JUN 19	28.89	3.0	0.65	0.97
JUN 20	28.89	4.0	0.63	1.00
JUN 21	32.22	6.6	0.40	0.95
JUN 22	29.44	5.0	0.61	0.73
JUN 23	30.56	5.3	0.48	0.31
JUN 24	31.67	6.9	0.39	0.99
JUN 25	26.67	5.2	0.56	0.68
JUN 26	23.33	4.3	0.59	1.00
JUN 27	25.00	4.7	0.60	0.93
JUN 28	29.44	5.4	0.49	0.73
JUN 29	25.56	5.3	0.85	0.16
JUN 30	17.22	5.1	1.00	0.00
JUL 1	15.00	4.1	1.00	0.00
JUL 2	18.89	3.1	0.90	0.08
JUL 3	22.78	6.5	0.88	0.73
JUL 4	27.22	6.5	0.80	0.97
JUL 5	28.33	6.8	0.77	0.95
JUL 6	28.89	7.1	0.70	1.00
JUL 7	25.56	5.2	0.82	0.44
JUL 8	23.89	3.2	0.91	0.31
JUL 9	21.67	2.5	0.97	0.44
JUL 10	23.33	2.4	0.85	0.99
JUL 11	22.78	3.7	0.91	0.44
JUL 12	24.44	6.0	0.82	0.93
JUL 13	27.78	3.8	0.75	0.93

Table A1 continued.

JUL 14	29.44	4.0	0.75	0.57
JUL 15	25.56	4.0	0.82	0.63
JUL 16	26.67	2.2	0.83	0.57
JUL 17	25.56	2.6	0.88	0.57
JUL 18	25.56	3.7	0.88	0.78
JUL 19	17.78	4.6	1.00	0.38
JUL 20	19.44	4.5	0.75	1.00
JUL 21	20.00	2.9	0.73	1.00
JUL 22	21.11	4.4	0.76	1.00
JUL 23	23.33	4.1	0.82	0.93
JUL 24	25.56	2.9	0.85	0.44
JUL 25	24.44	3.3	0.66	0.99
JUL 26	22.78	2.5	0.68	0.57
JUL 27	23.89	4.6	0.66	1.00
JUL 28	26.11	5.8	0.72	1.00
JUL 29	24.44	3.1	0.98	0.23
JUL 30	26.67	2.5	0.85	0.97
JUL 31	30.00	5.3	0.51	1.00
AUG 1	29.44	7.9	0.53	0.73
AUG 2	30.56	7.7	0.51	0.78
AUG 3	28.33	5.9	0.67	0.78
AUG 4	19.44	3.8	1.00	0.16
AUG 5	20.56	3.0	0.81	1.00
AUG 6	24.44	5.0	0.85	0.57
AUG 7	29.44	6.5	0.68	0.90
AUG 8	24.44	3.5	0.94	0.23
AUG 9	24.44	2.2	0.88	0.68
AUG 10	26.11	4.5	0.74	0.90
AUG 11	28.33	5.0	0.72	0.73
AUG 12	26.11	5.5	0.82	0.73
AUG 13	25.00	3.6	0.88	0.82
AUG 14	28.33	3.8	0.77	1.00
AUG 15	27.22	3.8	0.86	0.97
AUG 16	30.00	6.6	0.59	1.00
AUG 17	29.44	4.5	0.61	0.99
AUG 18	23.89	2.9	0.88	0.38
AUG 19	23.89	2.8	0.85	0.63
AUG 20	22.78	3.1	0.85	0.99
AUG 21	26.11	5.6	0.80	0.99
AUG 22	23.33	4.2	0.91	0.63
AUG 23	23.89	2.6	0.59	0.93
AUG 24	22.78	2.7	0.55	1.00
AUG 25	22.78	4.1	0.53	1.00
AUG 26	19.44	4.6	0.63	0.63
AUG 27	16.11	5.4	0.74	0.78
AUG 28	16.11	2.9	0.59	1.00
AUG 29	20.56	5.0	0.48	0.86
AUG 30	20.00	5.7	0.58	0.82
AUG 31	25.56	8.0	0.52	0.95

Table A2. Meteorological data incorporated in the central Platte River water temperature model for the summer of 1989 by daily time period.

Time Periods	Mean Air Temperature (°C)	Mean Wind Speed (m/sec)	Relative Humidity (decimal)	Percent Sunshine (decimal)
JUN 1	17.22	3.9	0.64	0.68
JUN 2	22.22	5.1	0.63	0.68
JUN 3	18.89	4.6	0.70	0.51
JUN 4	17.22	4.2	0.51	0.31
JUN 5	18.33	3.9	0.53	0.95
JUN 6	23.89	6.7	0.59	0.97
JUN 7	22.78	3.5	0.68	0.31
JUN 8	18.33	4.7	0.62	0.82
JUN 9	17.78	3.3	0.62	0.08
JUN 10	17.78	5.4	1.00	0.00
JUN 11	21.67	4.6	0.94	0.00
JUN 12	19.44	6.7	0.70	0.90
JUN 13	16.67	6.7	0.62	0.90
JUN 14	14.44	6.9	0.71	0.16
JUN 15	15.00	3.5	0.57	0.86
JUN 16	20.00	6.6	0.52	0.82
JUN 17	20.56	6.0	0.78	0.23
JUN 18	21.11	3.9	0.63	1.00
JUN 19	27.22	7.6	0.50	0.97
JUN 20	30.56	10.8	0.53	0.51
JUN 21	23.33	8.4	0.64	0.16
JUN 22	19.44	3.8	0.58	0.00
JUN 23	18.89	3.9	0.65	0.51
JUN 24	20.56	5.7	0.97	0.00
JUN 25	22.22	4.8	0.94	0.00
JUN 26	23.33	3.7	0.82	0.44
JUN 27	22.22	2.7	0.94	0.82
JUN 28	23.33	4.3	0.88	0.63
JUN 29	23.89	4.6	0.79	0.82
JUN 30	21.11	3.7	0.97	0.00
JUL 1	23.89	4.2	0.94	0.73
JUL 2	26.67	3.3	0.85	0.73
JUL 3	25.56	3.3	0.88	0.95
JUL 4	26.67	3.5	0.85	0.90
JUL 5	26.67	5.4	0.77	1.00
JUL 6	28.33	4.4	0.70	1.00
JUL 7	27.78	3.4	0.70	0.95
JUL 8	30.00	6.4	0.53	0.99
JUL 9	30.00	6.9	0.57	1.00
JUL 10	28.89	6.0	0.65	0.97
JUL 11	27.22	4.9	0.83	0.16
JUL 12	26.67	4.4	0.88	0.73
JUL 13	25.00	2.5	0.82	0.31

Table A2 continued.

JUL	14	25.00	5.2	0.77	0.23
JUL	15	18.33	4.6	1.00	0.00
JUL	16	18.33	3.9	1.00	0.08
JUL	17	23.33	4.7	0.91	0.23
JUL	18	21.67	5.3	0.84	0.63
JUL	19	23.33	4.7	0.71	0.97
JUL	20	21.67	3.8	0.76	1.00
JUL	21	22.22	3.3	0.79	1.00
JUL	22	20.00	2.5	0.90	0.90
JUL	23	20.56	2.5	0.94	0.78
JUL	24	22.22	3.9	0.85	0.93
JUL	25	23.89	4.8	0.85	0.86
JUL	26	25.56	5.3	0.74	0.93
JUL	27	26.67	4.6	0.74	0.95
JUL	28	26.11	5.1	0.80	0.97
JUL	29	29.44	4.4	0.70	0.78
JUL	30	26.67	4.7	0.88	0.57
JUL	31	26.11	3.1	0.85	0.38
AUG	1	26.11	5.8	0.85	0.82
AUG	2	27.78	6.9	0.80	0.23
AUG	3	28.89	5.1	0.75	0.82
AUG	4	28.89	4.4	0.65	0.68
AUG	5	26.11	3.6	0.58	1.00
AUG	6	16.67	4.6	0.93	0.63
AUG	7	16.67	2.9	0.69	1.00
AUG	8	18.89	3.5	0.62	1.00
AUG	9	20.56	4.7	0.63	0.63
AUG	10	23.33	5.8	0.59	0.38
AUG	11	21.67	5.3	0.73	0.86
AUG	12	22.78	4.5	0.76	0.08
AUG	13	22.78	4.5	0.88	0.44
AUG	14	23.89	4.3	0.71	0.78
AUG	15	20.00	2.5	0.94	0.08
AUG	16	20.56	3.1	0.87	0.73
AUG	17	23.33	5.3	0.74	0.51
AUG	18	24.44	6.9	0.77	0.44
AUG	19	24.44	3.7	0.77	0.90
AUG	20	22.78	3.3	0.85	0.86
AUG	21	26.11	4.2	0.85	0.44
AUG	22	23.89	4.2	0.88	0.23
AUG	23	25.56	3.7	0.64	0.97
AUG	24	23.33	5.6	0.88	0.44
AUG	25	24.44	6.3	0.94	0.44
AUG	26	25.00	4.2	0.91	0.68
AUG	27	20.00	4.8	1.00	0.16
AUG	28	24.44	2.9	0.94	0.08
AUG	29	23.89	3.9	0.98	0.23
AUG	30	22.22	6.1	1.00	0.68
AUG	31	27.22	6.2	0.80	0.86

Table A3. Meteorological data incorporated in the central Platte River water temperature model for the summer of 1990 by daily time period.

Time Periods		Mean Air Temperature (°C)	Mean Wind Speed (m/sec)	Relative Humidity (decimal)	Percent Sunshine (decimal)
JUN	1	22.22	7.7	0.91	0.23
JUN	2	16.67	7.6	0.72	0.68
JUN	3	14.44	7.1	0.66	0.97
JUN	4	16.11	6.8	0.80	0.90
JUN	5	21.11	5.0	0.70	0.90
JUN	6	21.11	5.7	0.54	0.82
JUN	7	19.44	5.2	0.75	0.57
JUN	8	22.22	4.1	0.73	0.90
JUN	9	22.78	2.4	0.68	0.90
JUN	10	23.89	8.4	0.82	0.16
JUN	11	28.33	10.8	0.61	0.86
JUN	12	25.56	5.5	0.69	0.51
JUN	13	23.89	4.6	0.55	0.86
JUN	14	21.67	6.7	0.82	0.38
JUN	15	22.78	8.2	0.94	0.38
JUN	16	25.00	4.9	0.88	0.57
JUN	17	22.22	4.2	0.71	1.00
JUN	18	22.78	5.7	0.79	0.93
JUN	19	24.44	5.4	0.82	0.63
JUN	20	22.22	3.5	0.66	0.95
JUN	21	16.67	4.8	1.00	0.16
JUN	22	18.33	5.2	0.72	0.97
JUN	23	18.89	2.8	0.78	0.86
JUN	24	24.44	5.0	0.71	0.90
JUN	25	26.67	4.2	0.72	0.90
JUN	26	25.56	2.9	0.80	0.97
JUN	27	27.78	5.5	0.77	0.99
JUN	28	30.56	4.7	0.68	0.97
JUN	29	28.89	2.7	0.80	0.86
JUN	30	28.33	3.1	0.86	0.82
JUL	1	29.44	5.5	0.80	0.95
JUL	2	32.22	5.3	0.42	0.99
JUL	3	32.78	6.4	0.40	1.00
JUL	4	26.11	5.4	0.67	0.82
JUL	5	20.56	3.5	0.97	0.00
JUL	6	24.44	7.3	0.98	0.31
JUL	7	30.00	7.2	0.61	0.73
JUL	8	25.00	5.4	0.71	0.86
JUL	9	23.33	4.5	0.85	0.51
JUL	10	20.56	4.3	1.00	0.00
JUL	11	20.56	3.1	0.87	0.93
JUL	12	16.67	5.9	0.83	0.63
JUL	13	16.67	2.9	0.75	0.90

Table A3 continued.

JUL	14	17.78	2.4	0.67	0.97
JUL	15	21.67	3.7	0.59	0.86
JUL	16	23.89	5.2	0.69	0.90
JUL	17	27.78	6.5	0.63	0.57
JUL	18	27.22	5.5	0.70	0.90
JUL	19	23.33	3.3	0.94	0.00
JUL	20	22.78	3.7	0.91	0.00
JUL	21	20.56	5.2	0.81	0.00
JUL	22	20.00	2.9	0.70	0.82
JUL	23	21.67	3.6	0.71	0.86
JUL	24	23.89	6.4	0.74	0.63
JUL	25	21.67	5.6	1.00	0.08
JUL	26	23.89	4.4	0.94	0.38
JUL	27	26.11	4.3	0.88	0.68
JUL	28	22.78	4.4	0.94	0.31
JUL	29	22.78	3.7	0.82	0.86
JUL	30	21.67	3.5	0.84	0.73
JUL	31	20.56	3.3	0.81	0.95
AUG	1	22.22	5.4	0.76	0.99
AUG	2	22.78	4.9	0.91	0.16
AUG	3	23.33	2.7	0.82	0.31
AUG	4	20.56	4.0	0.84	0.63
AUG	5	18.33	2.9	0.75	0.78
AUG	6	18.33	2.4	0.78	0.97
AUG	7	20.00	5.7	0.70	0.95
AUG	8	22.22	5.7	0.73	0.99
AUG	9	22.78	2.2	0.88	0.90
AUG	10	22.78	2.8	0.97	0.44
AUG	11	22.78	3.3	0.88	0.44
AUG	12	22.22	3.6	0.85	0.51
AUG	13	21.11	3.3	0.87	0.68
AUG	14	21.11	4.2	0.97	0.08
AUG	15	23.33	3.4	0.97	0.38
AUG	16	26.11	4.5	0.88	0.68
AUG	17	27.78	6.7	0.72	0.95
AUG	18	26.11	4.6	0.82	0.90
AUG	19	22.22	4.1	0.94	0.23
AUG	20	22.22	3.2	0.85	0.51
AUG	21	22.22	3.5	0.97	0.68
AUG	22	26.11	6.0	0.91	0.78
AUG	23	27.22	4.4	0.77	0.90
AUG	24	23.89	3.7	0.94	0.68
AUG	25	26.11	4.2	0.85	1.00
AUG	26	27.78	4.4	0.70	0.95
AUG	27	27.78	3.8	0.72	0.68
AUG	28	24.44	3.3	0.94	0.63
AUG	29	25.00	2.7	0.77	0.93
AUG	30	26.67	4.9	0.72	1.00
AUG	31	30.56	3.7	0.51	1.00

APPENDIX B

JOB CONTROL FILE FOR CENTRAL PLATTE RIVER WATER TEMPERATURE MODEL.

Table B1. Final version of job contol file used to calibrate the water temperature model for the central Platte River.

```
JOB CONTROL FILE: 1989/90 PLATTE RIVER (OVER-CHAP) TEMP STUDY
n-value =vary, new max coeff adj, new W vs Q, run 15
FFFFFFFFTTTTFFFFFFFF                                    FFFFFFFFTTFFFFFFFFFTFFFFF
      2.      0.      0.     92.      0.     12.     16.      3.     27.      0.
      0.     10.      4.      1.      1.      0.      0.      0.      1.      0.
      4.      2.      0.      0.      4.      1.      2.      1.     92.      0.
    0.00  0.0000    0.00  0.0000   13.84  0.1238   -5.68  1.9797    0.00  0.0000
    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
8990TME.PRN     8990MET.PRN     8990SKT.PRN     8990STR9.PRN    8990STD.PRN
8990HDR.PRN     8990HYD4.PRN    8990SHD.PRN
STR NAME             0.0     0.0
STR NAME             0.0     0.0
STR NAME             0.0     0.0
STR NAME             0.0     0.0
STR NAME             0.0     0.0
STR NAME             0.0     0.0
STR NAME             0.0     0.0
STR NAME             0.0     0.0
STR NAME             0.0     0.0
STR NAME             0.0     0.0
```

APPENDIX C

OBSERVED AND SIMULATED MEAN DAILY DISCHARGE AT THE USGS GRAND ISLAND GAGE FOR THE SUMMER OF 1988, 1989, AND 1990.

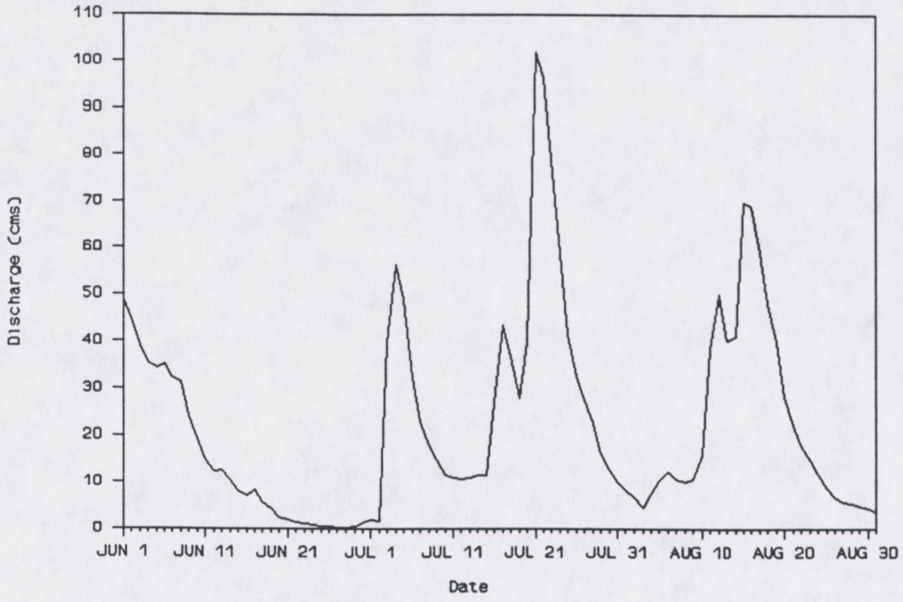


Figure C1. Platte River mean daily discharge (cms) at the USGS Grand Island gage during the summer of 1988.

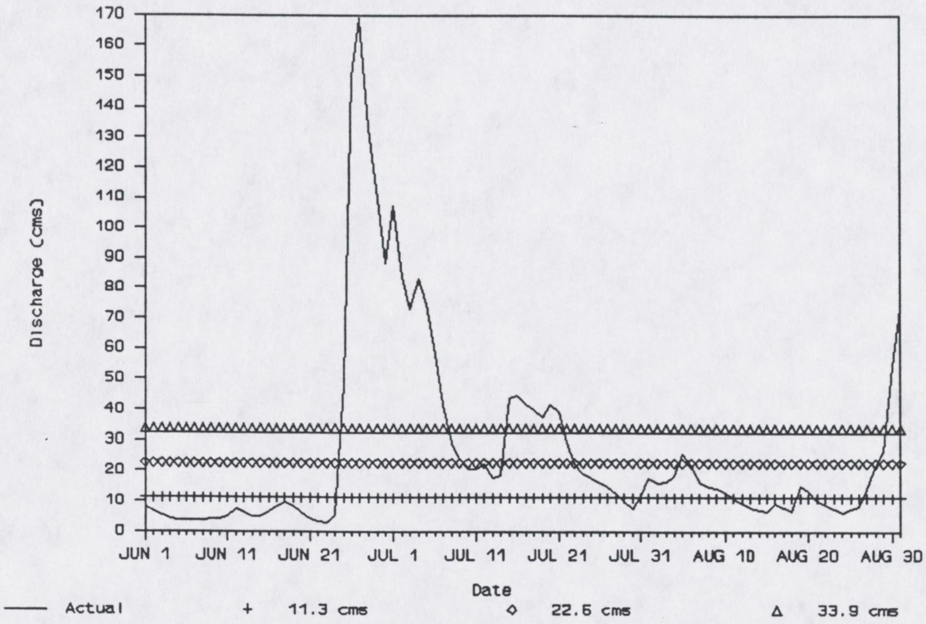


Figure C2. Platte River mean daily discharge (cms) and mean daily discharges simulated (11.3, 22.6, and 33.9 cms) at the USGS Grand Island gage during the summer of 1989.

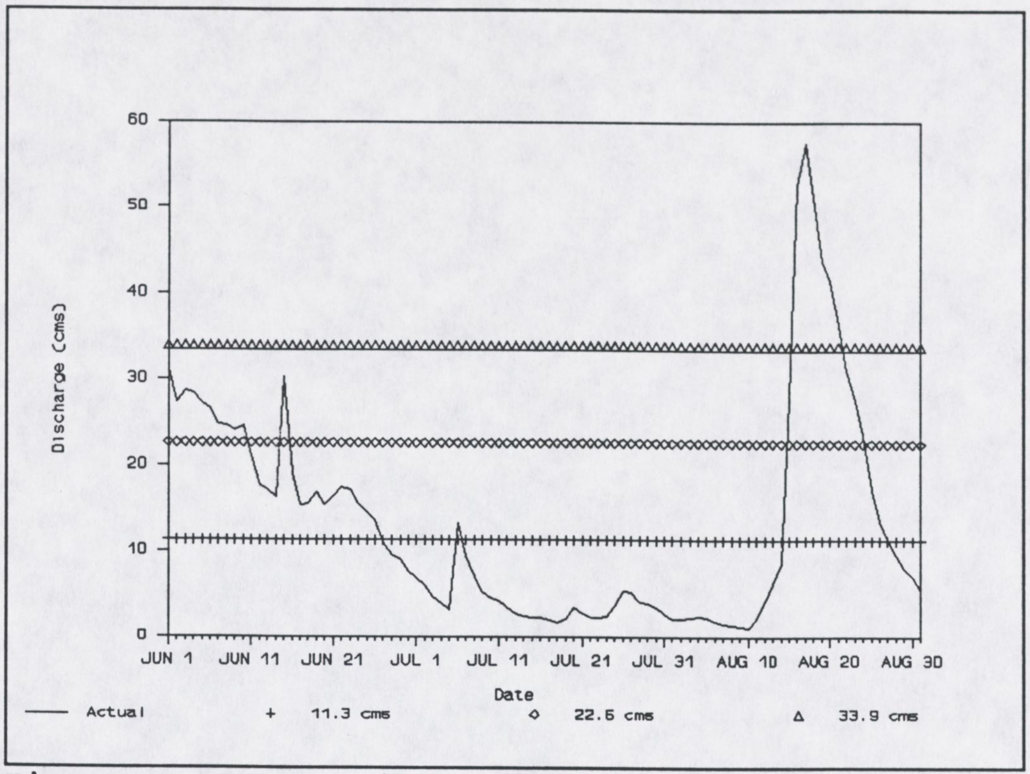


Figure C3. Platte River mean daily discharge (cms) and mean daily discharges simulated (11.3, 22.6, and 33.9 cms) at the USGS Grand Island gage during the summer of 1990.

APPENDIX D

WETTED WIDTH VERSUS FLOW RELATIONSHIP AND REGRESSION STATISTICS FOR EACH STREAM GEOMETRY NODE.

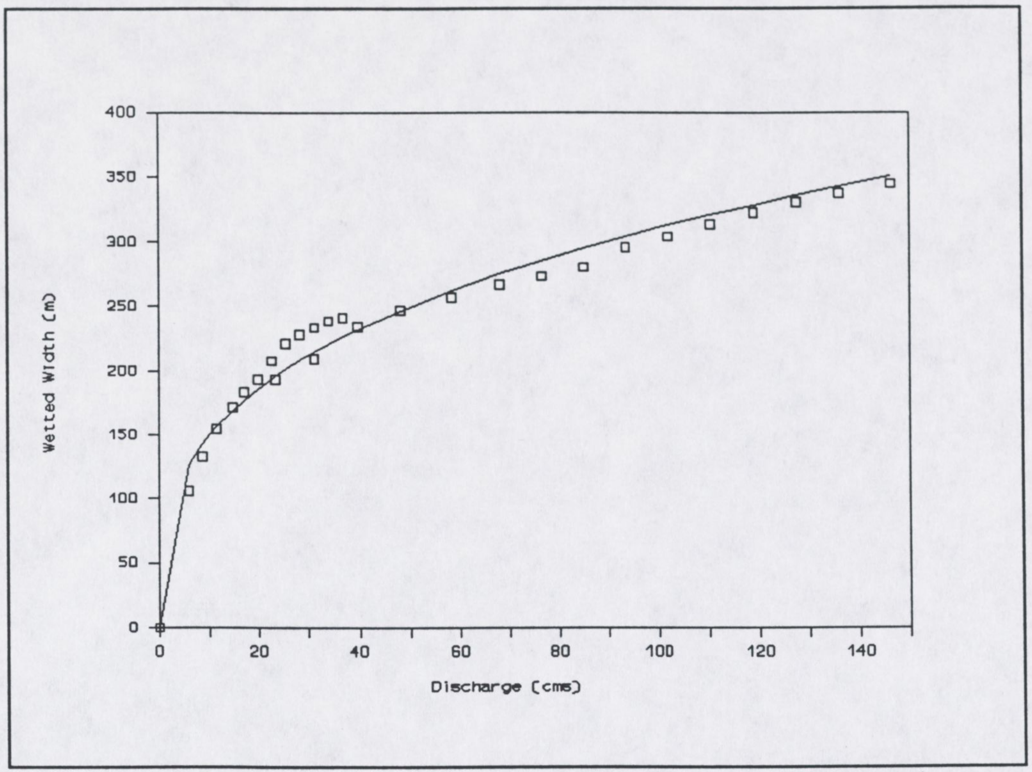


Figure D1. Wetted width versus flow relationship for the Overton Gage (Seg3) and Odessa (Seg5) stream geometry nodes. ($Y = 71.960 * X^{.317831}$) (R^2=.959386)

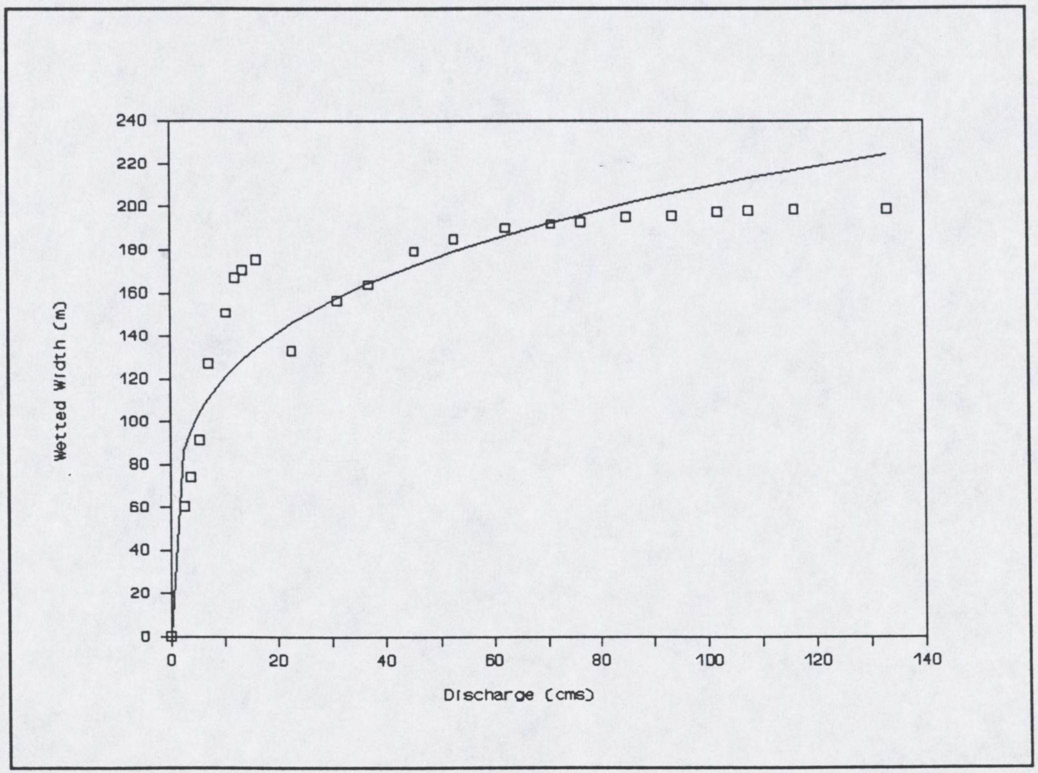


Figure D2. Wetted width versus flow relationship for the Elm Creek (Seg4A) stream geometry node. ($Y = 68.837 * X^{.241681}$) (R^2=.769427)

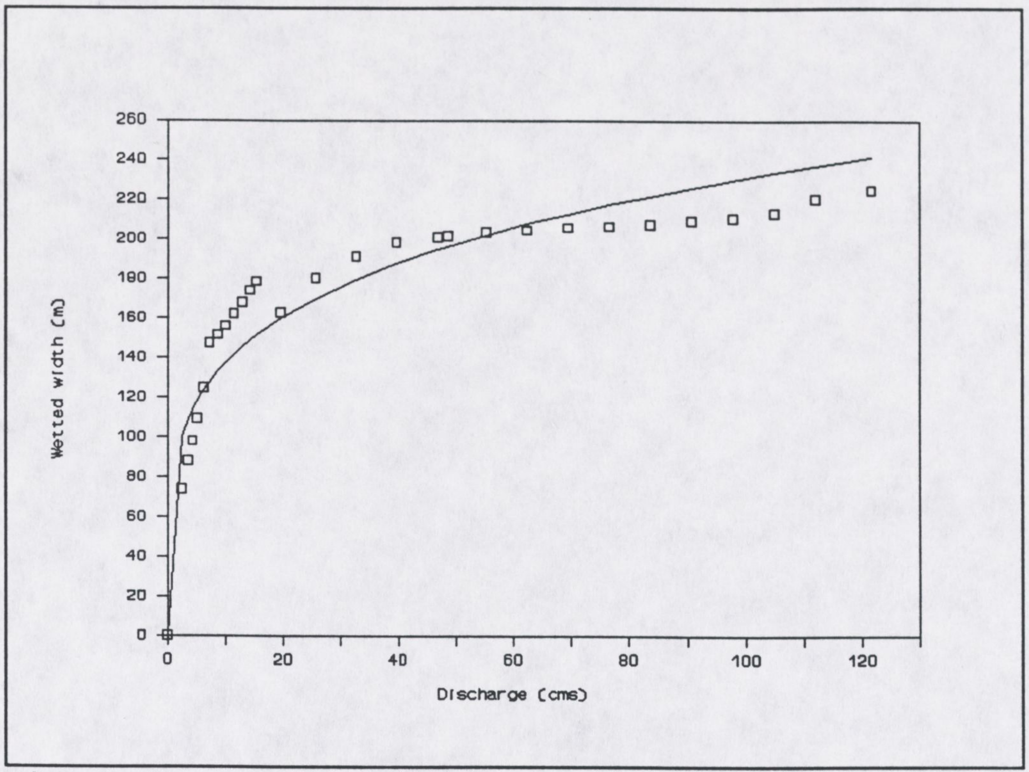


Figure D3. Wetted width versus flow relationship for the Elm Creek (Seg4B) stream geometry node. ($Y = 82.174 * X^{.224516}$) (R^2=.841789)

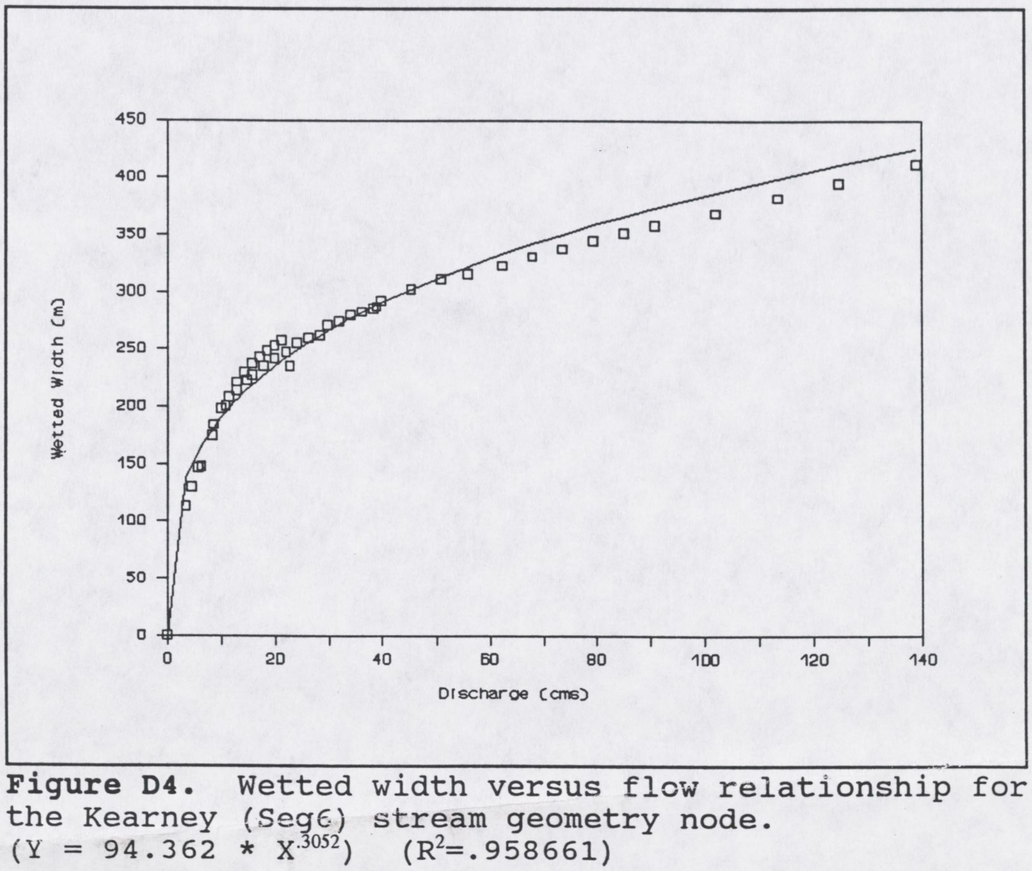


Figure D4. Wetted width versus flow relationship for the Kearney (Seg6) stream geometry node. ($Y = 94.362 * X^{.3052}$) (R^2=.958661)

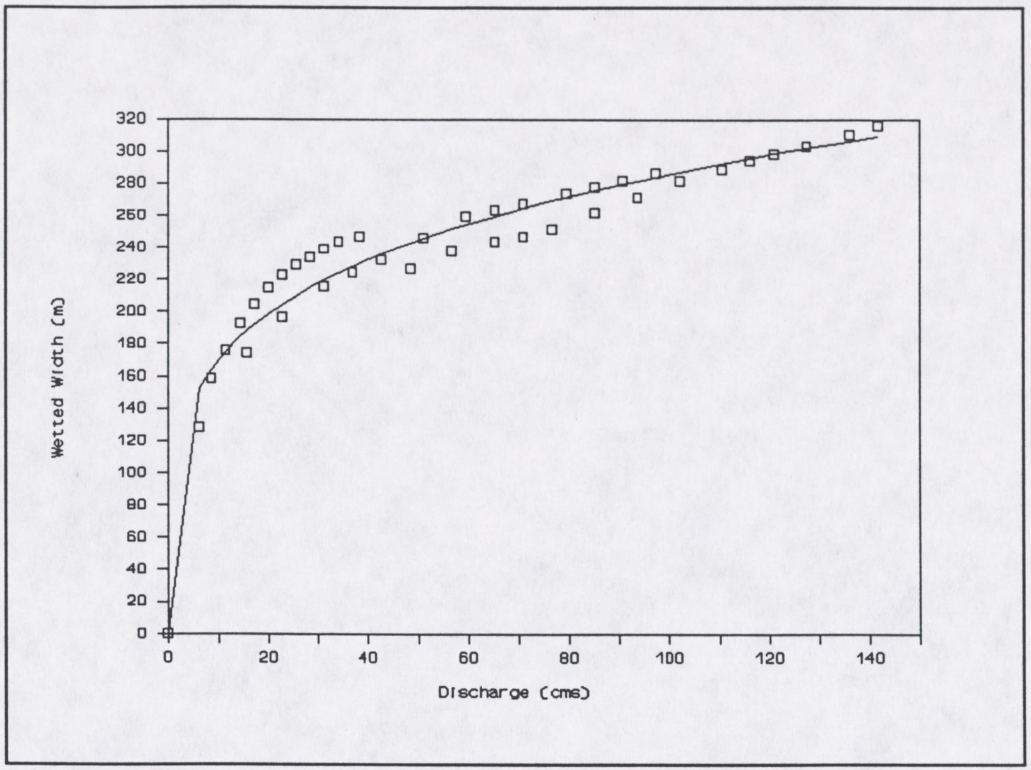


Figure D5. Wetted width versus flow relationship for the Gibbon (Seg8C) stream geometry node.
(Y = 101.280 * $X^{.225425}$) (R^2=.915587)

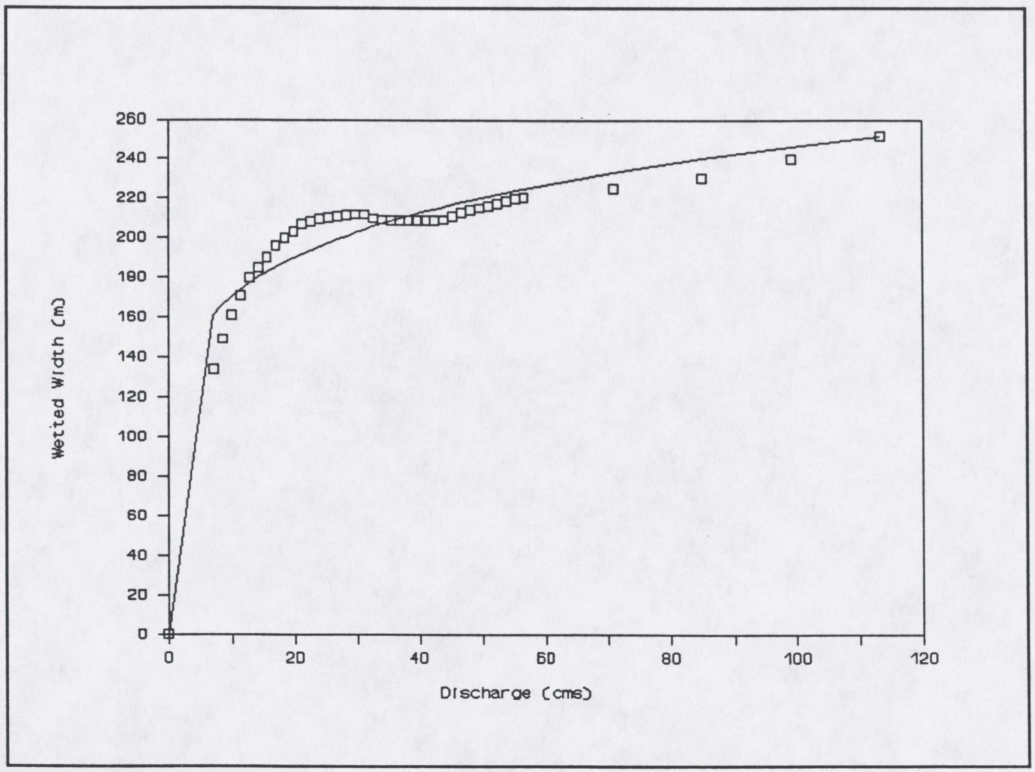


Figure D6. Wetted width versus flow relationship for the Shelton (Seg8A) stream geometry node.
(Y = 117.428 * $X^{.161004}$) (R^2=.810652)

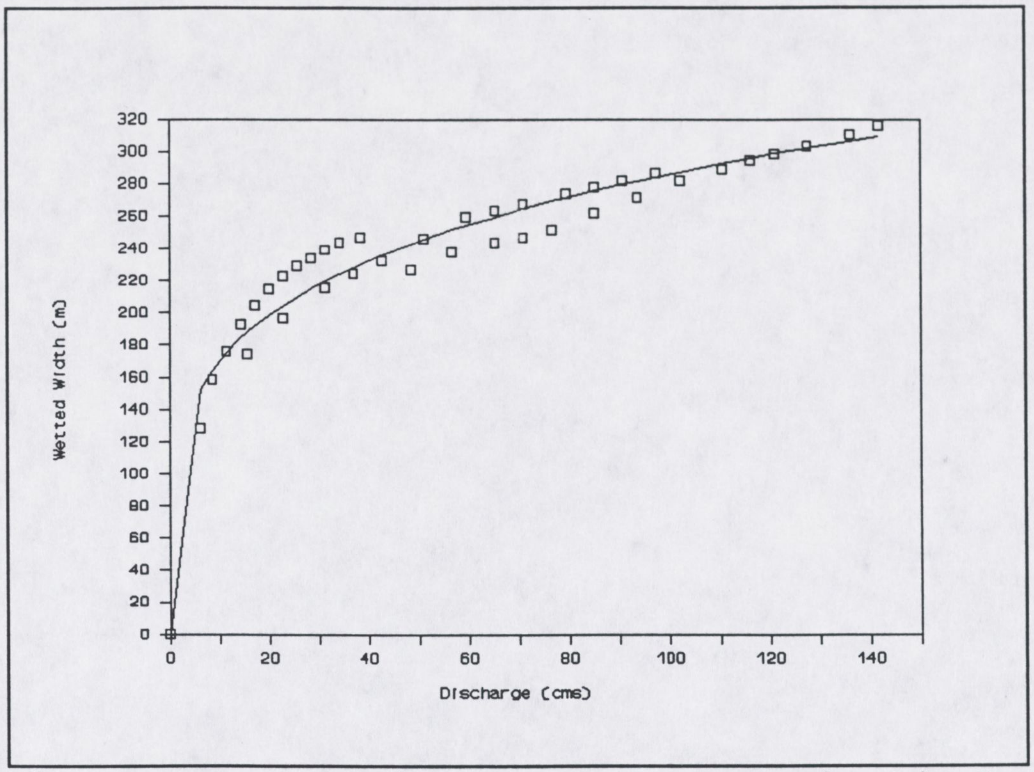


Figure D7. Wetted width versus flow relationship for the Shelton (Seg8B) stream geometry node. (Y = 110.441 * $X^{.233547}$) (R^2=.800689)

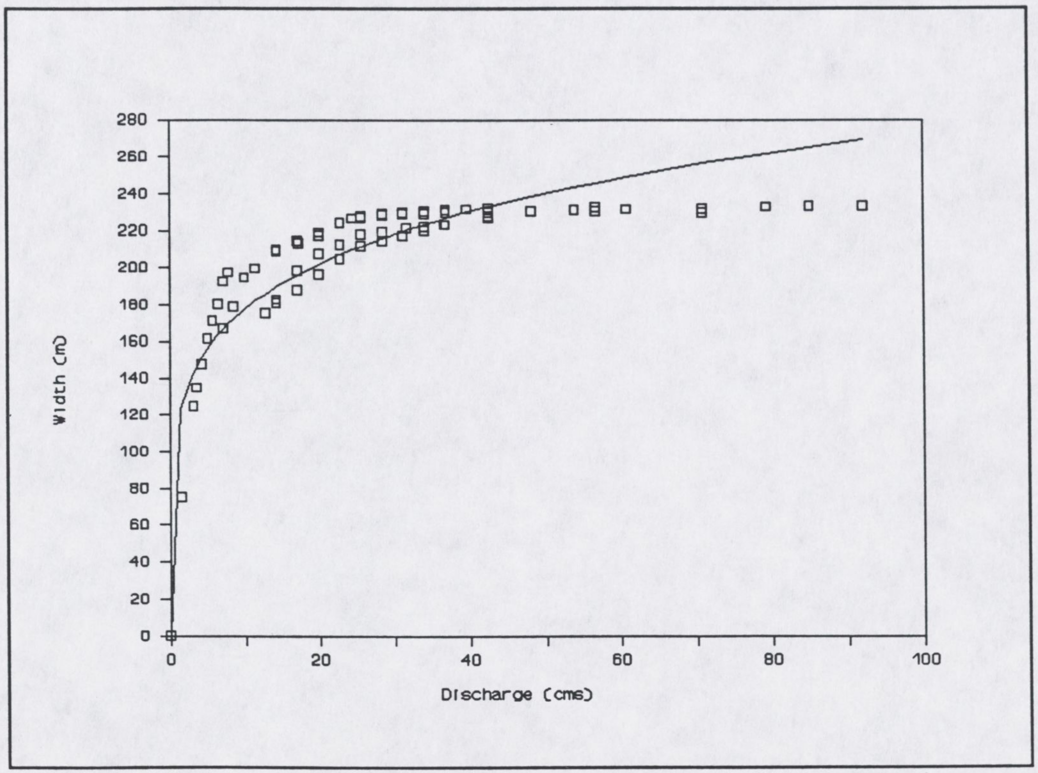


Figure D8. Wetted width versus flow relationship for the Wood River (Seg9) stream geometry node. (Y = 115.501 * $X^{.187232}$) (R^2=.756835)

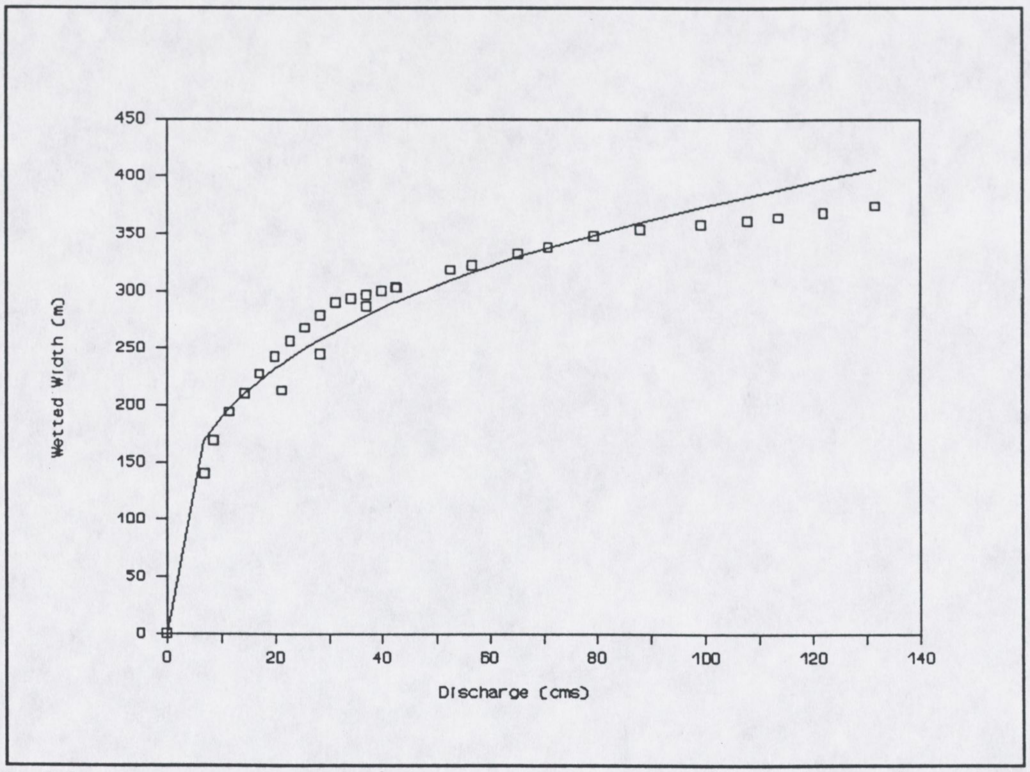


Table D9. Wetted width versus flow relationship for the Grand Island (Seg12B) stream geometry node. ($Y = 96.069 * X^{.295265}$) (R^2=.930904)

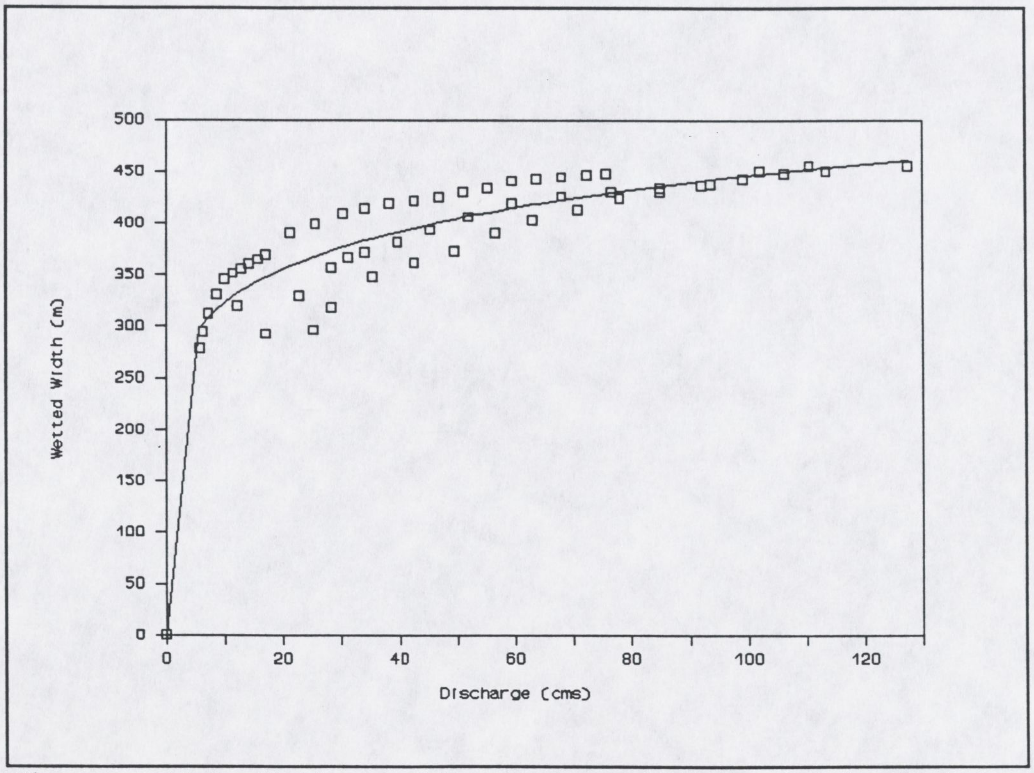


Figure D10. Wetted width versus flow relationship for the Phillips (Seg12A) stream geometry node. ($Y = 233.729 * X^{.140376}$) ($R^2$=.749645)

APPENDIX E

OBSERVED AND PREDICTED DAILY MEAN WATER TEMPERATURES AT EACH VALIDATION NODE WITHIN THE CENTRAL PLATTE RIVER STUDY AREA DURING THE SUMMER OF 1989 AND 1990.

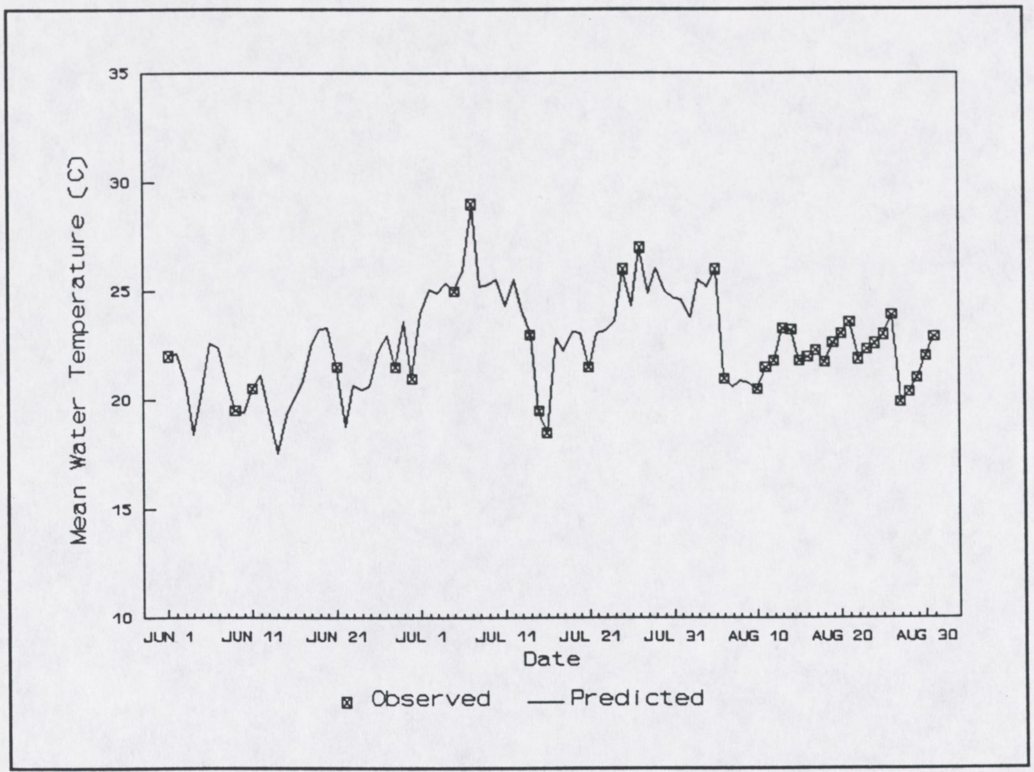


Figure E1. Results of final calibration run showing observed and predicted mean daily water temperature (°C) for the Overton thermograph during 1989.

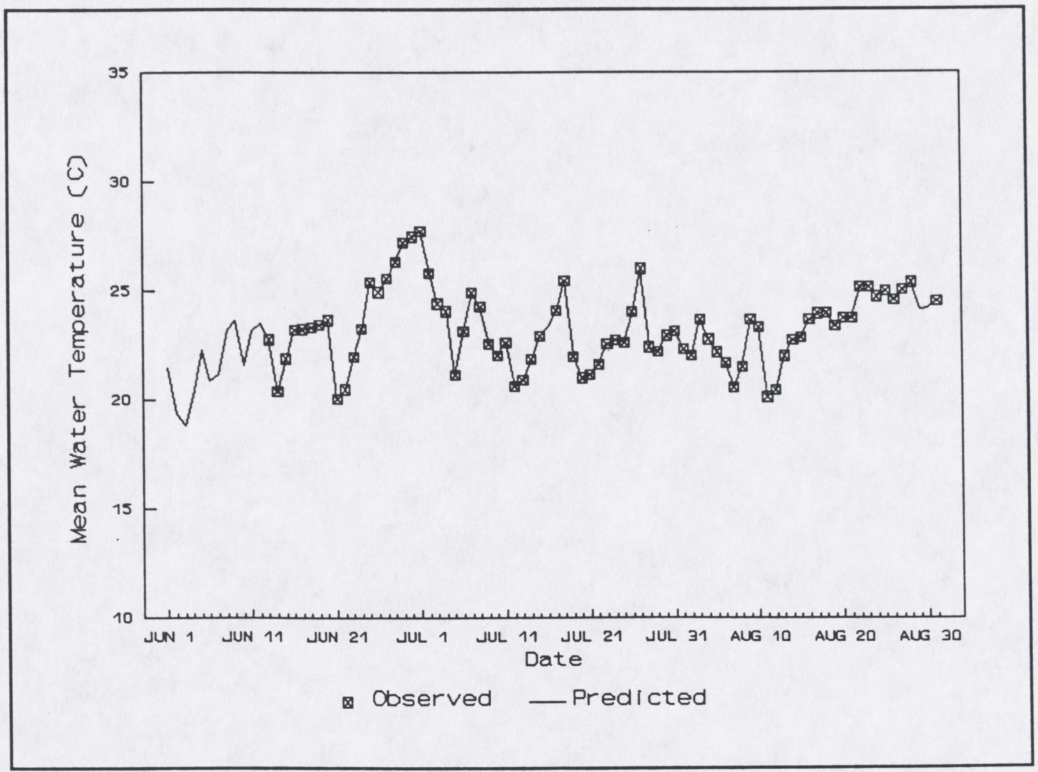


Figure E2. Results of final calibration run showing observed and predicted mean daily water temperature (°C) for the Overton thermograph during 1990.

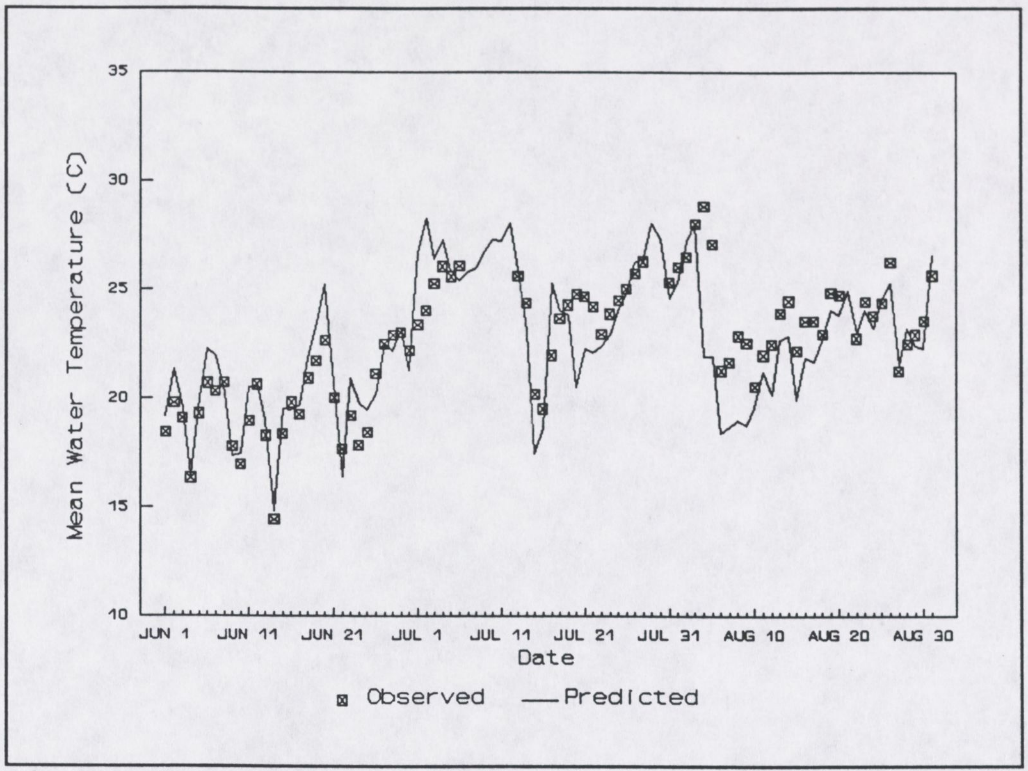


Figure E3. Results of final calibration run showing observed and predicted mean daily water temperature (°C) for the Odessa thermograph during 1989.

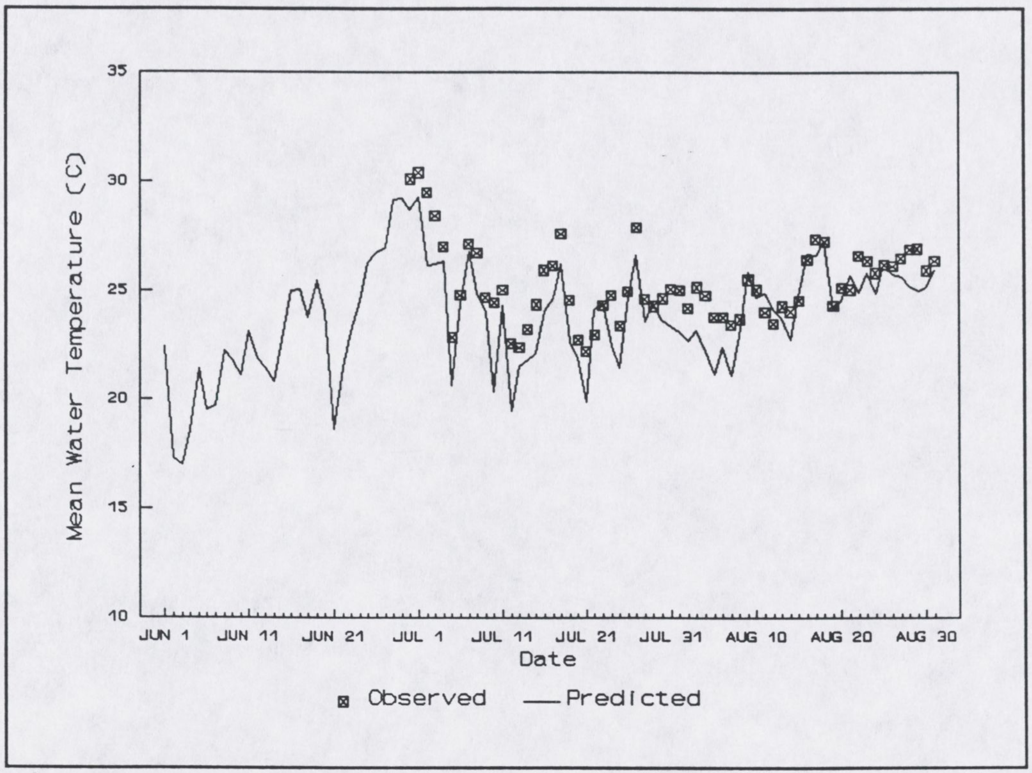


Figure E4. Results of final calibration run showing observed and predicted mean daily water temperature (°C) for the Odessa thermograph during 1990.

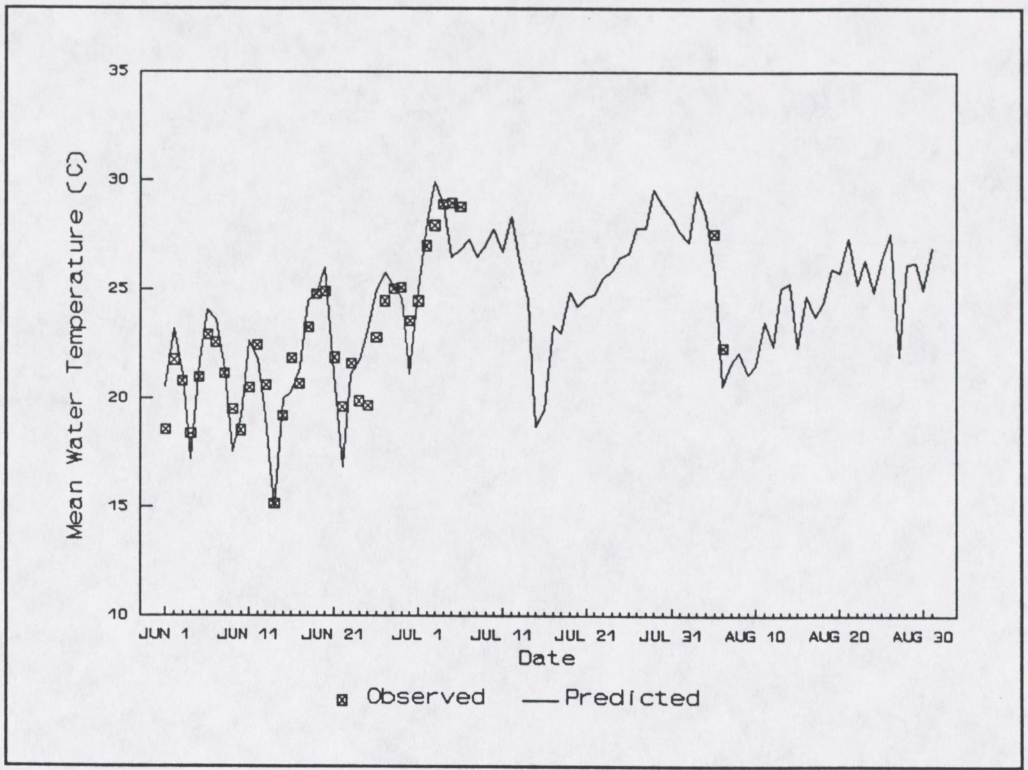


Figure E5. Results of final calibration run showing observed and predicted mean daily water temperature (°C) for the Shelton thermograph during 1989.

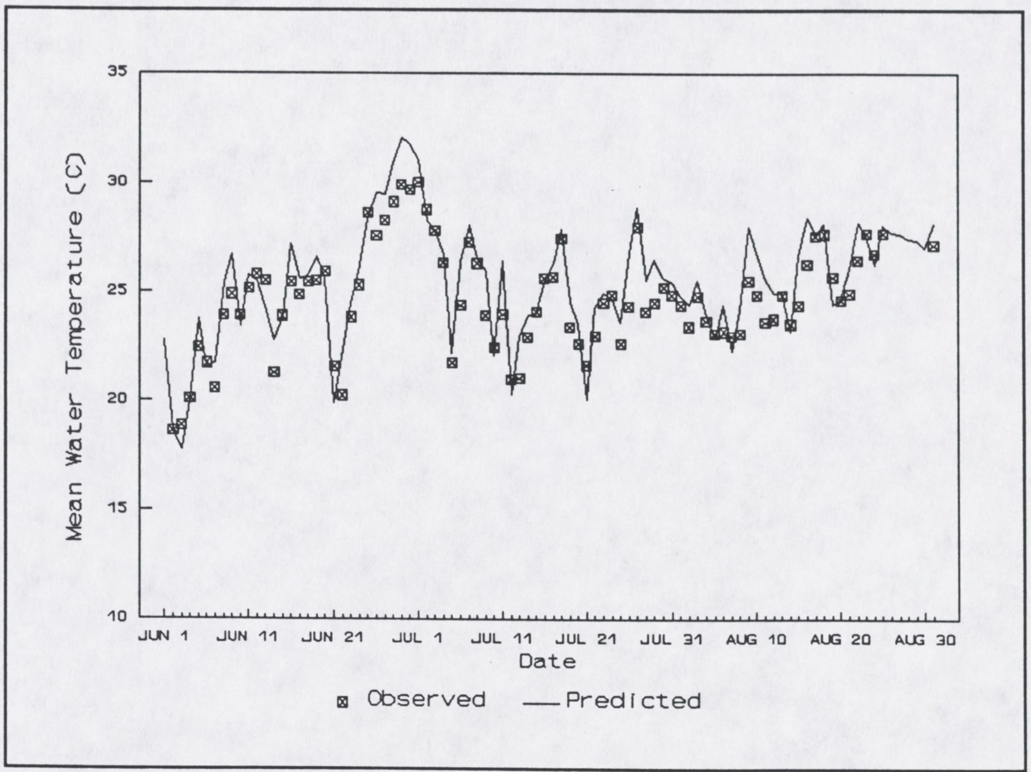


Figure E6. Results of final calibration run showing observed and predicted mean daily water temperature (°C) for the Shelton thermograph during 1990.

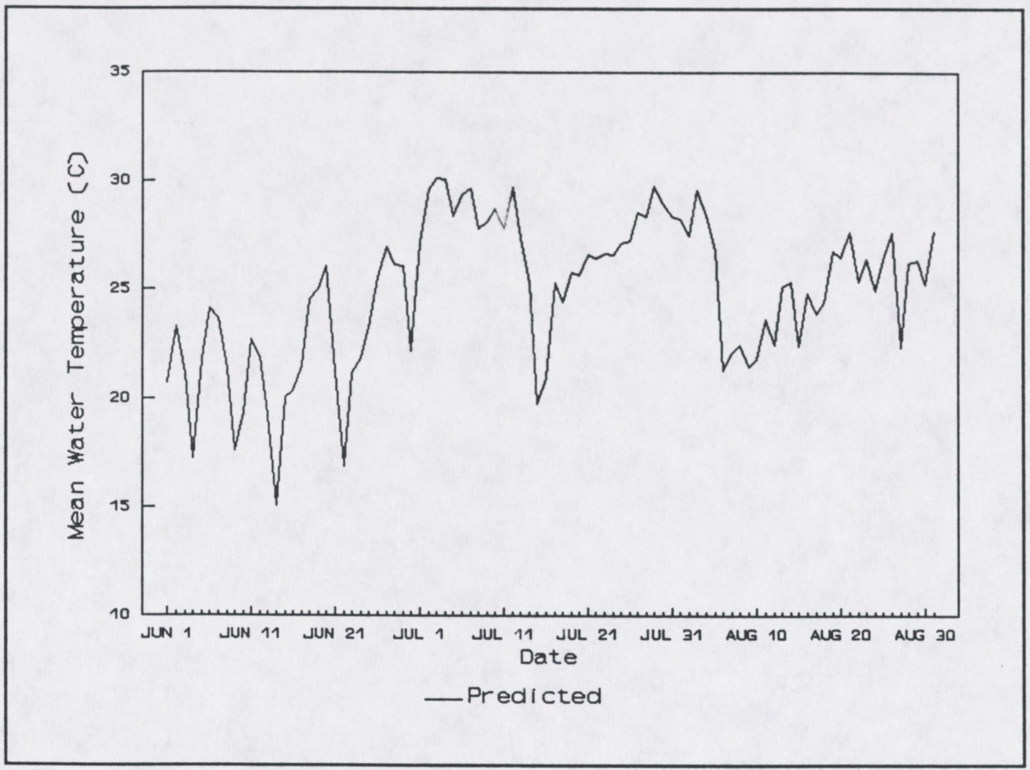


Figure E7. Results of final calibration run showing predicted mean daily water temperature (°C) for the Mormon Island thermograph during 1989.

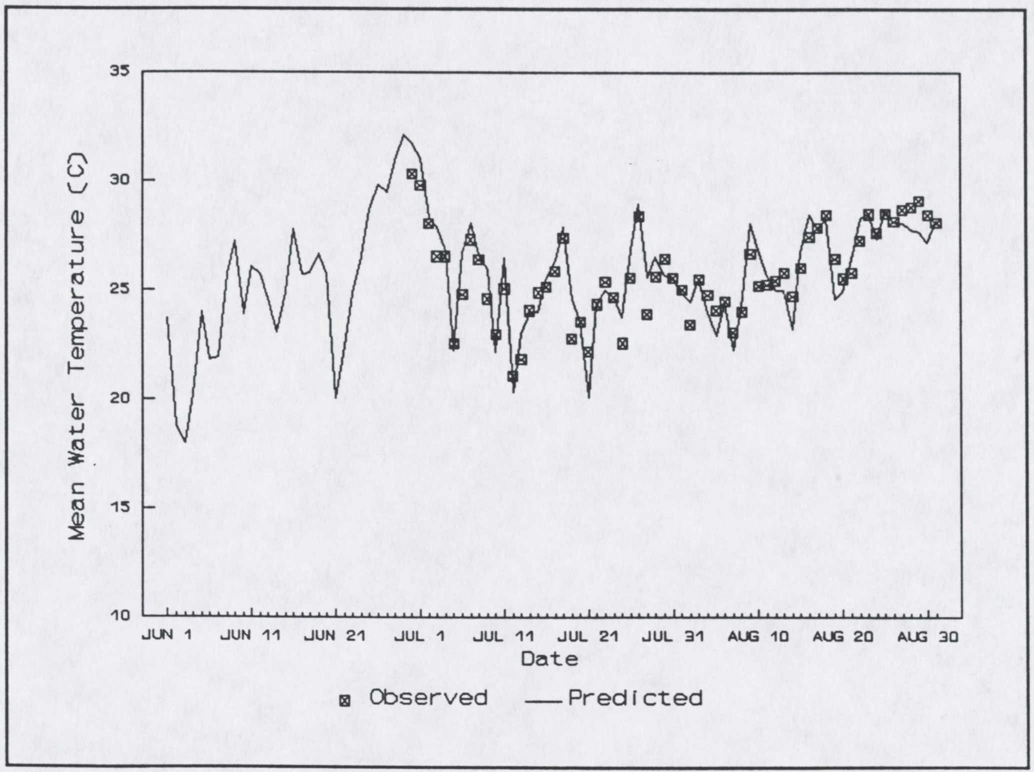


Figure E8. Results of final calibration run showing observed and predicted mean daily water temperature (°C) for the Mormon Island thermograph during 1990.

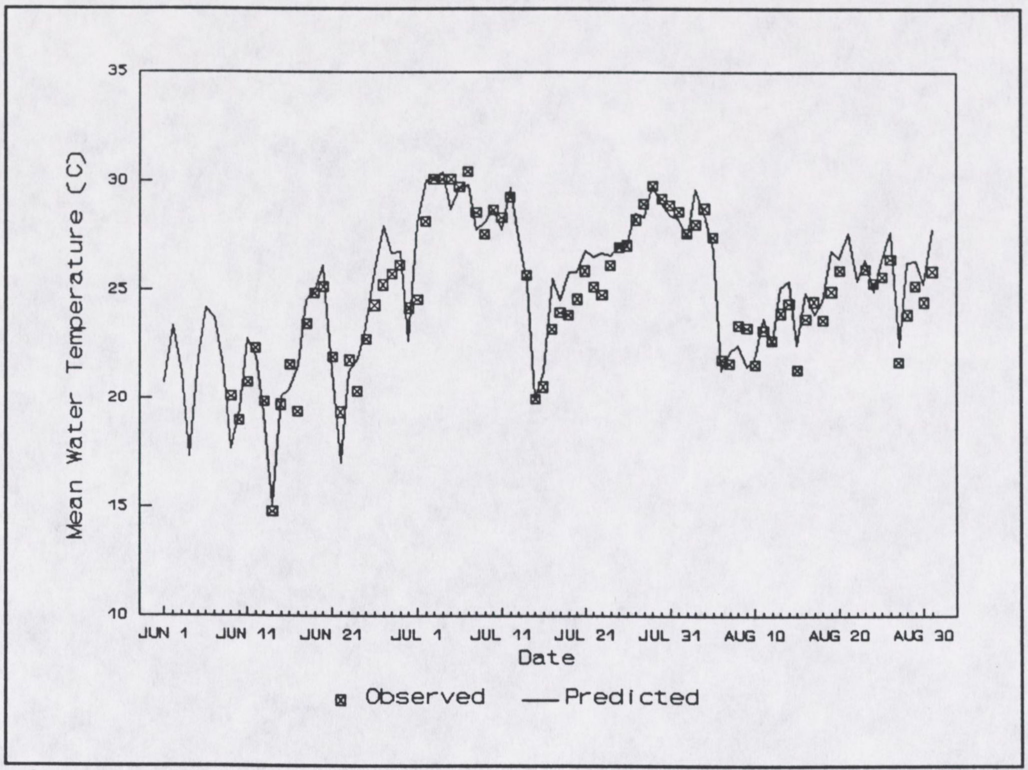


Figure E9. Results of final calibration run showing observed and predicted mean daily water temperature (°C) for the Phillips thermograph during 1989.

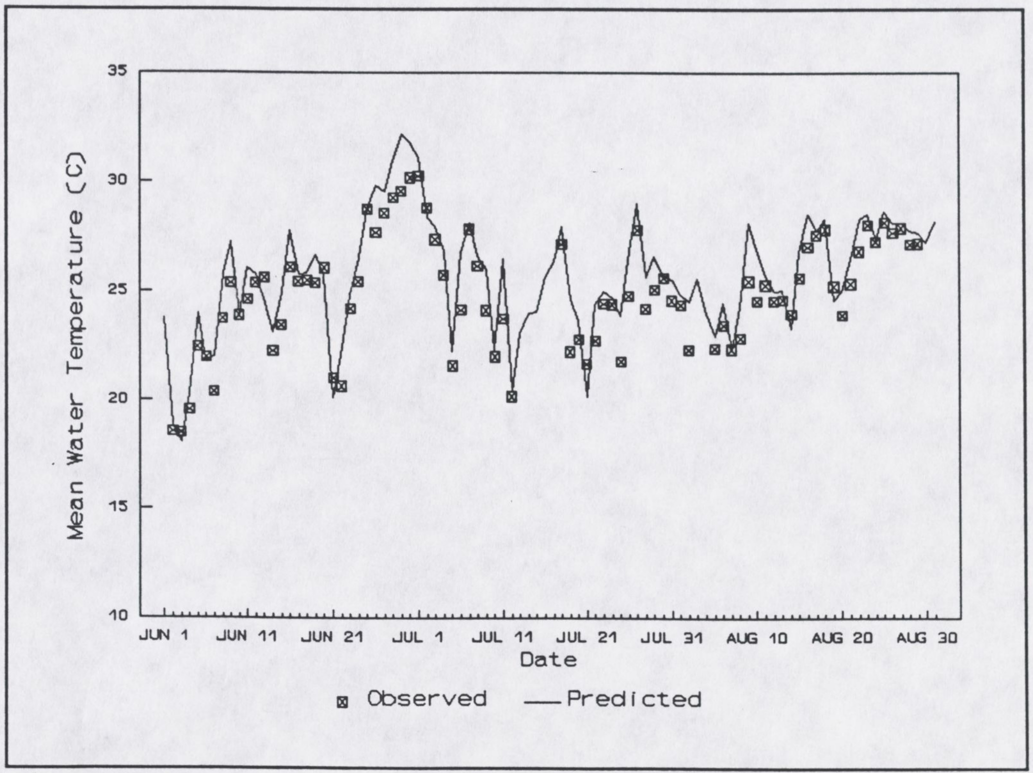


Figure E10. Results of final calibration run showing observed and predicted mean daily water temperature (°C) for the Phillips thermograph during 1990.

APPENDIX F

OBSERVED AND PREDICTED DAILY MAXIMUM WATER TEMPERATURES AT EACH VALIDATION NODE WITHIN THE CENTRAL PLATTE RIVER STUDY AREA DURING THE SUMMER OF 1989 AND 1990.

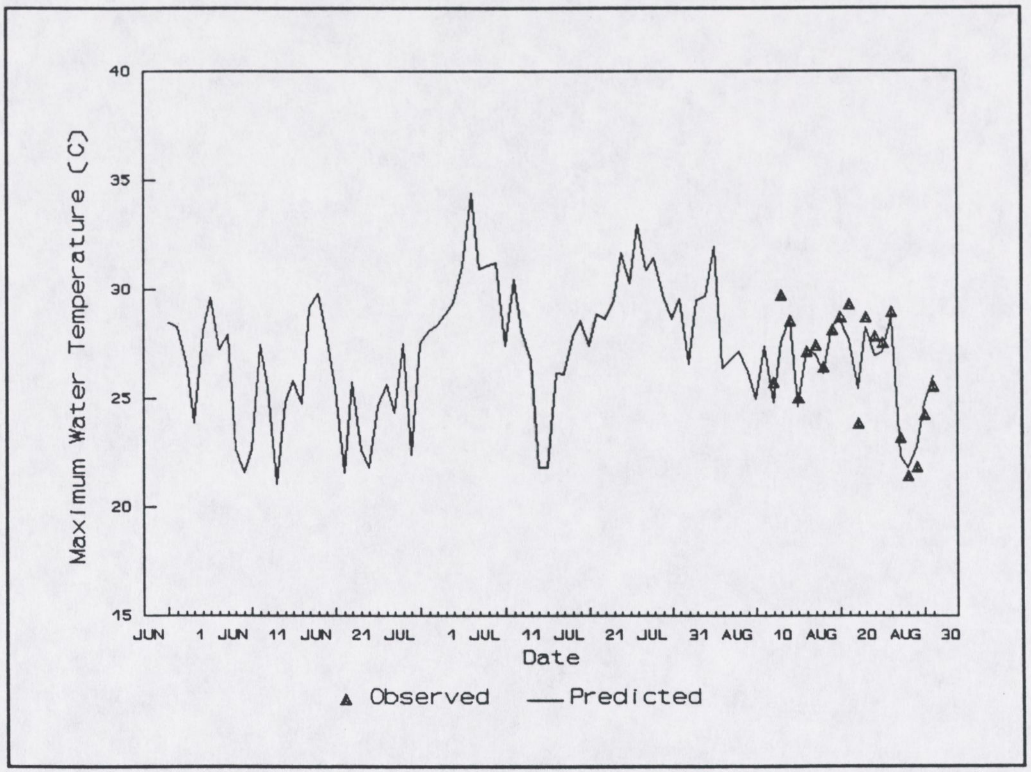


Figure F1. Results of final calibration run showing observed and predicted maximum daily water temperature (°C) for the Overton thermograph during 1989.

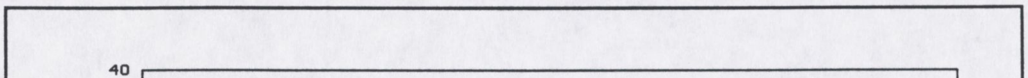


Figure F2. Results of final calibration run showing observed and predicted maximum daily water temperature (°C) for the Overton thermograph during 1990.

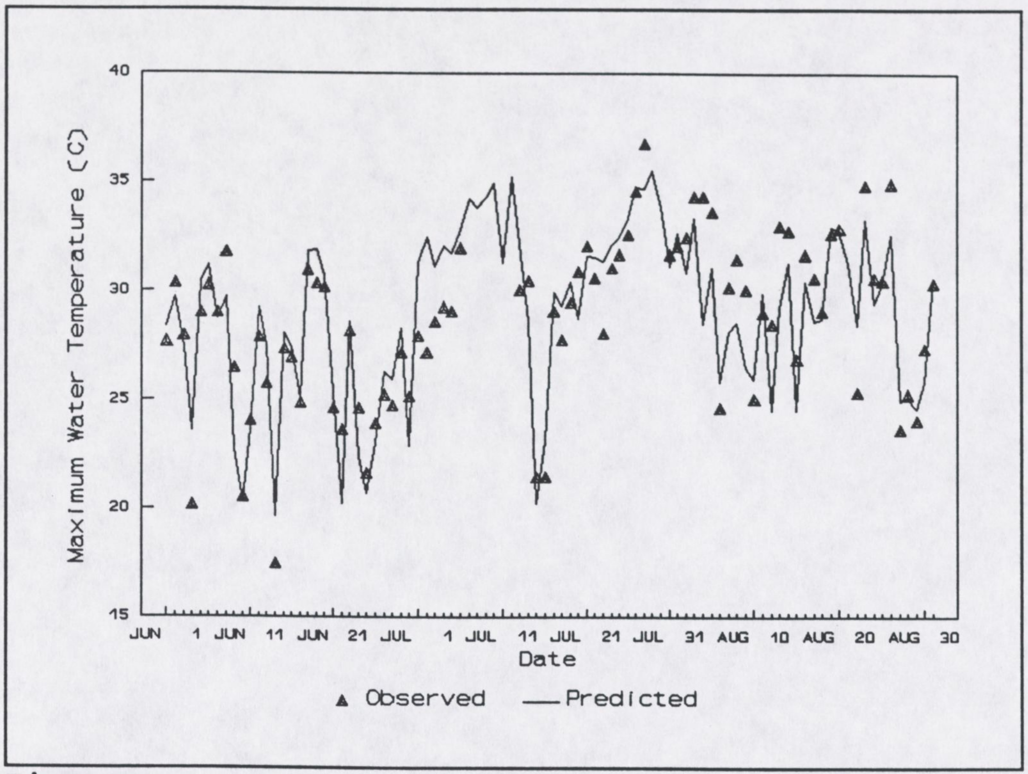


Figure F3. Results of final calibration run showing observed and predicted maximum daily water temperature (°C) for the Odessa thermograph during 1989.

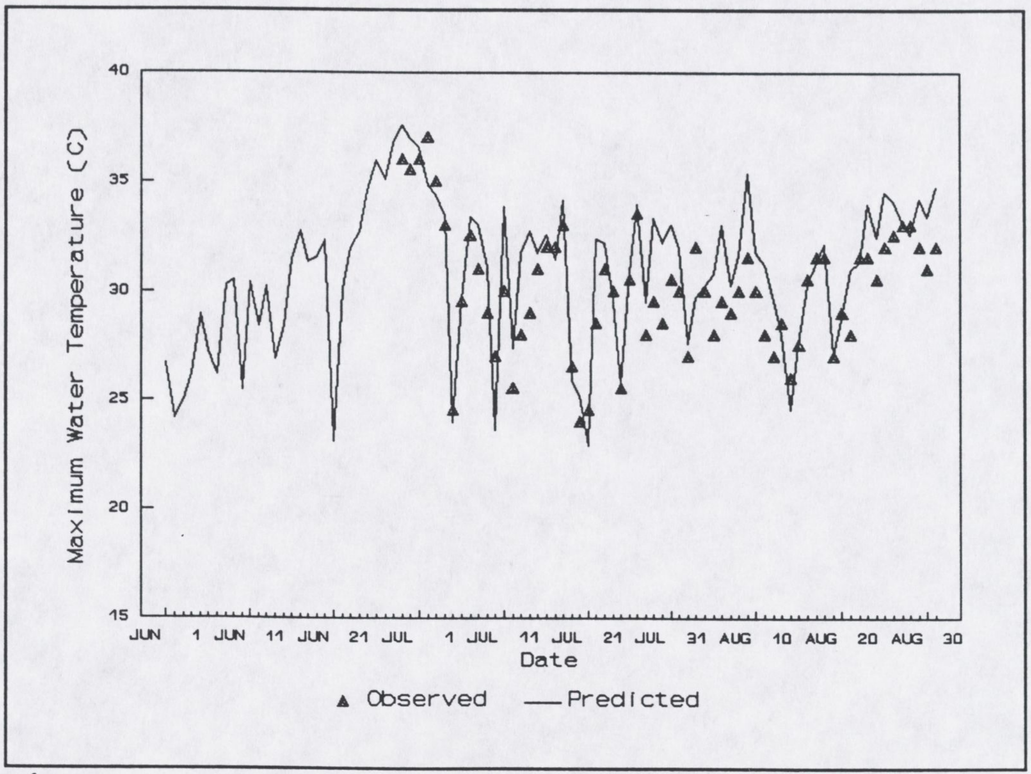


Figure F4. Results of final calibration run showing observed and predicted maximum daily water temperature (°C) for the Odessa thermograph during 1990.

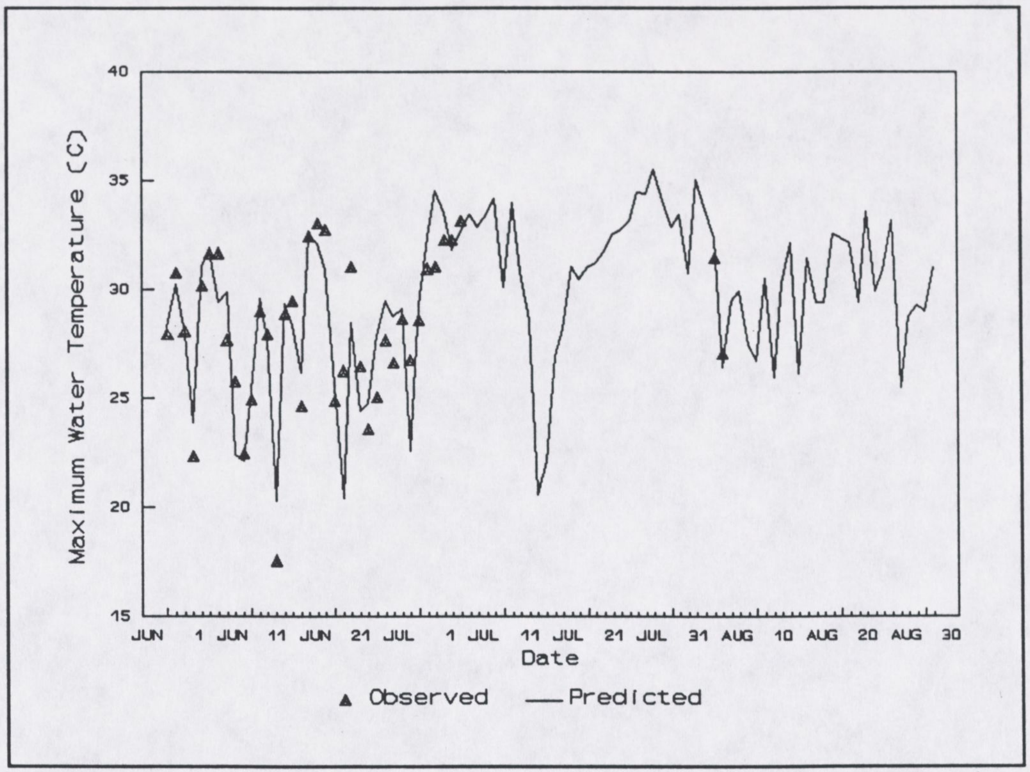


Figure F5. Results of final calibration run showing observed and predicted maximum daily water temperature (°C) for the Shelton thermograph during 1989.

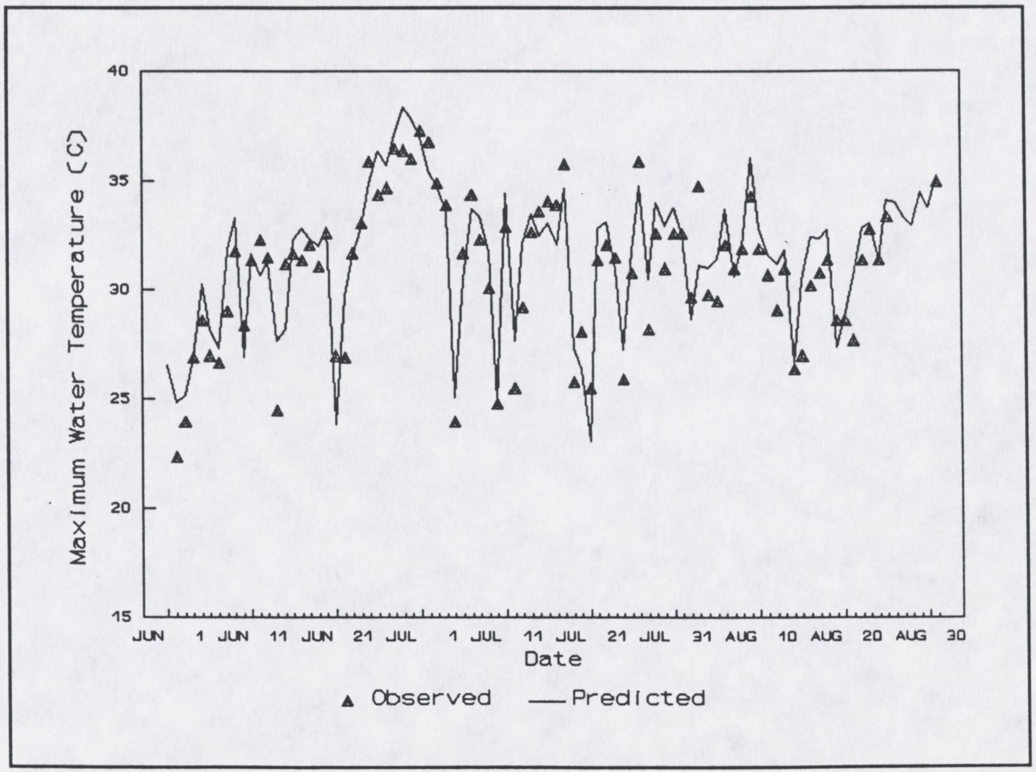


Figure F6. Results of final calibration run showing observed and predicted maximum daily water temperature (°C) for the Shelton thermograph during 1990.

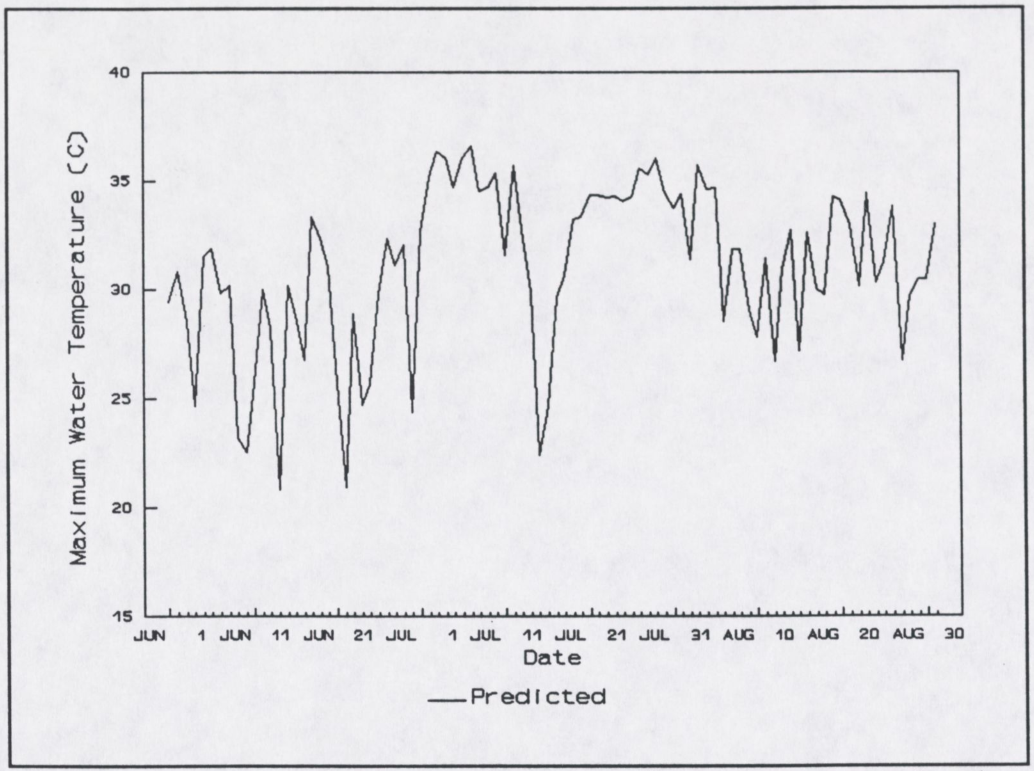


Figure F7. Results of final calibration run showing predicted maximum daily water temperature (°C) for the Mormon Island thermograph during 1989.

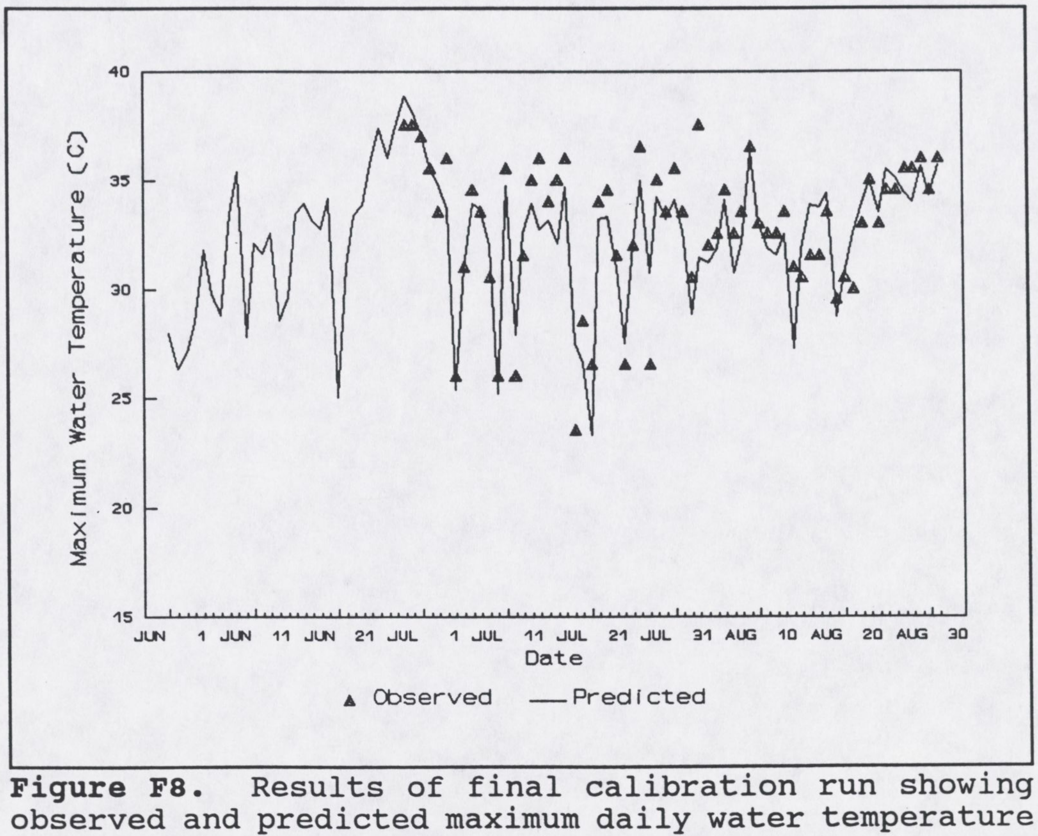


Figure F8. Results of final calibration run showing observed and predicted maximum daily water temperature (°C) for the Mormon Island thermograph during 1990.

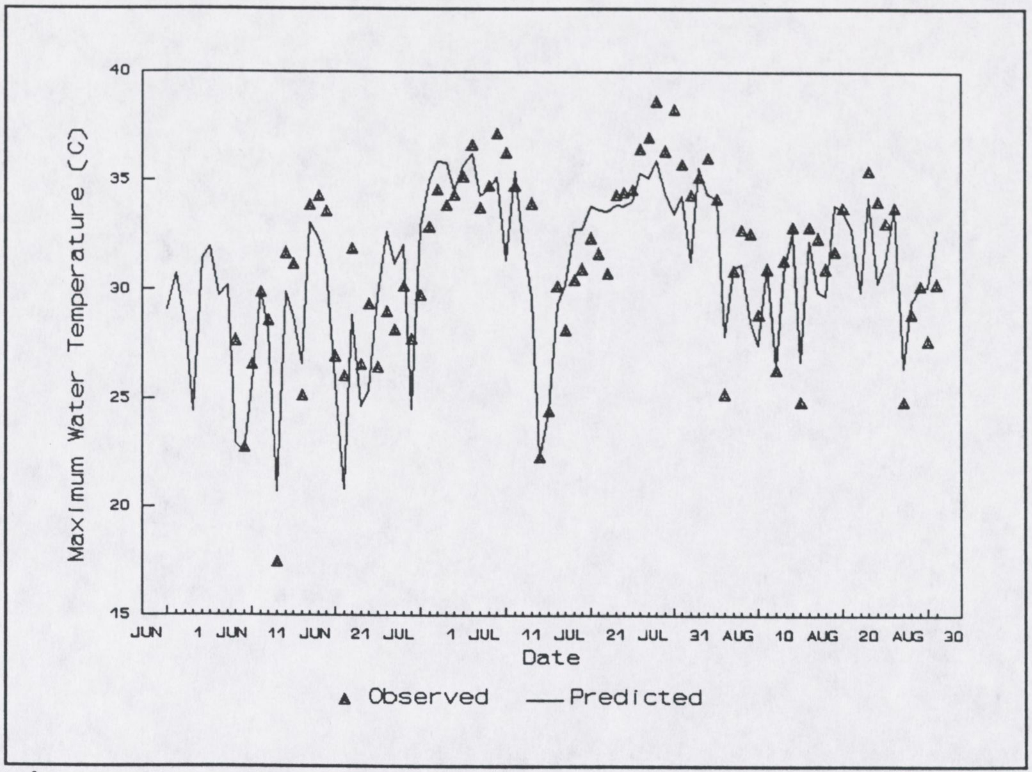
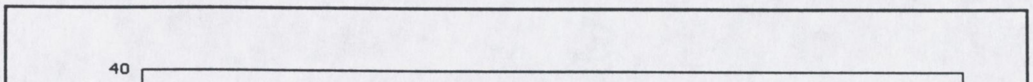


Figure F9. Results of final calibration run showing observed and predicted maximum daily water temperature (°C) for the Phillips thermograph during 1989.



APPENDIX G

RELATIONSHIP BETWEEN PREDICTED AND OBSERVED MAXIMUM WATER TEMPERATURE FOR EACH VALIDATION NODE.

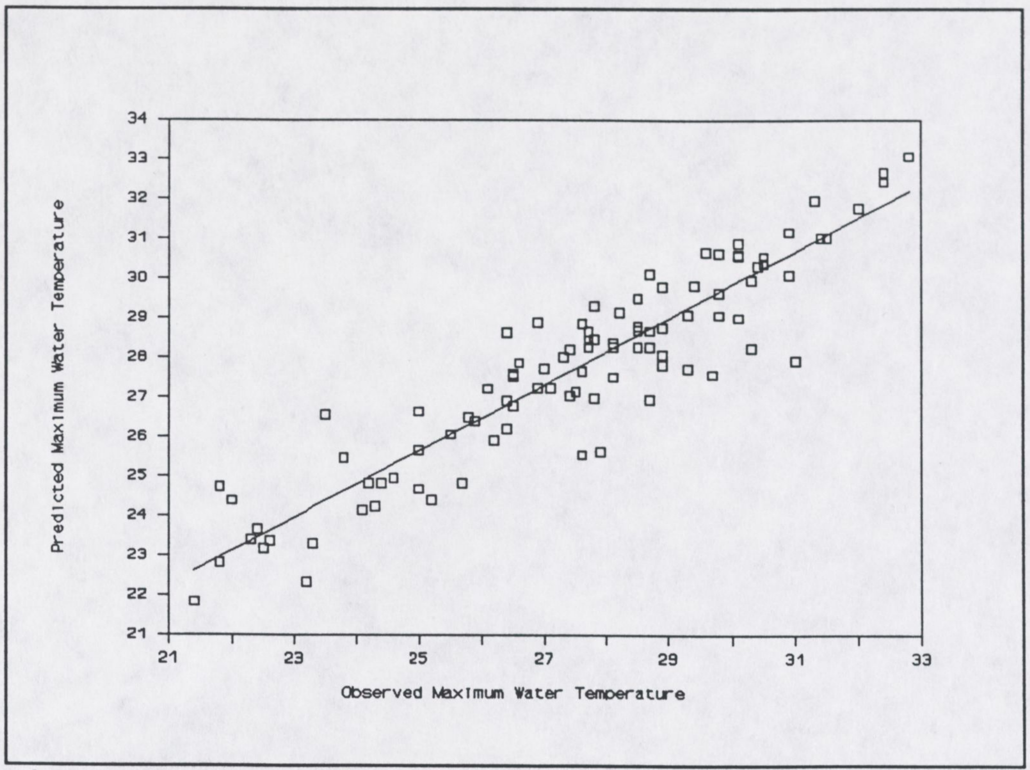


Figure G1. Relationship between predicted and observed maximum water temperature for the Overton thermograph. (Y = 4.616274 + (X * 0.841086)) (R^2=.85305) (N=97)

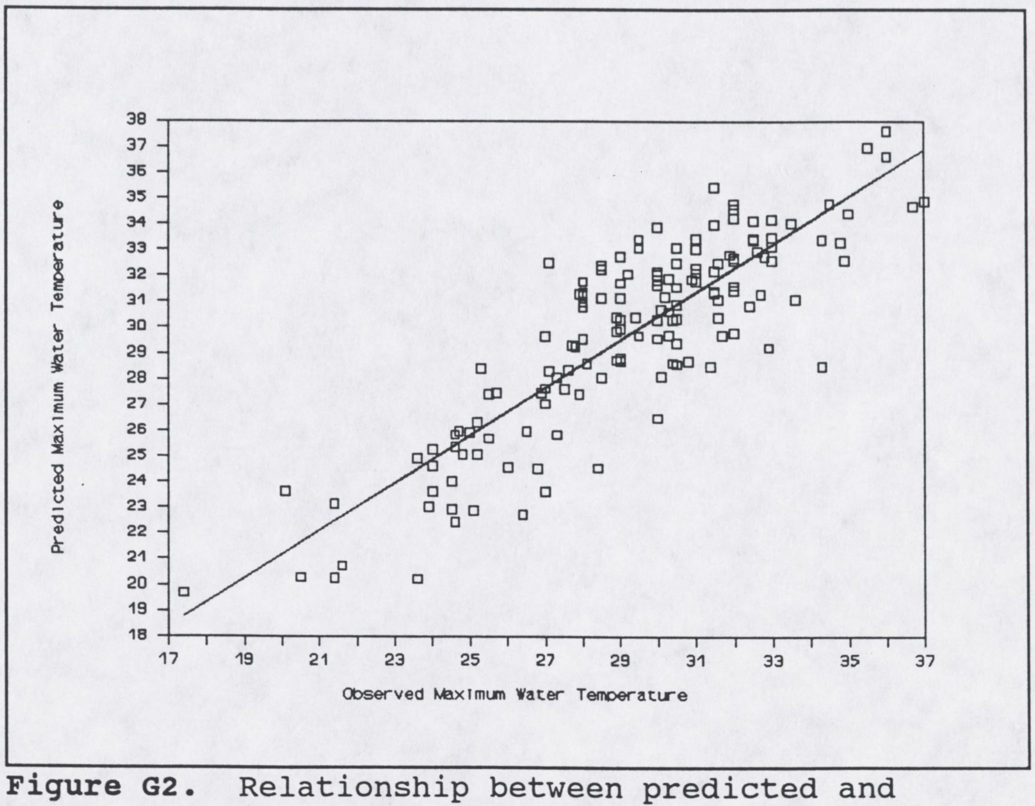


Figure G2. Relationship between predicted and observed maximum water temperature for the Odessa thermograph. (Y = 2.711671 + (X * 0.924158)) (R^2=.74344) (N = 147)

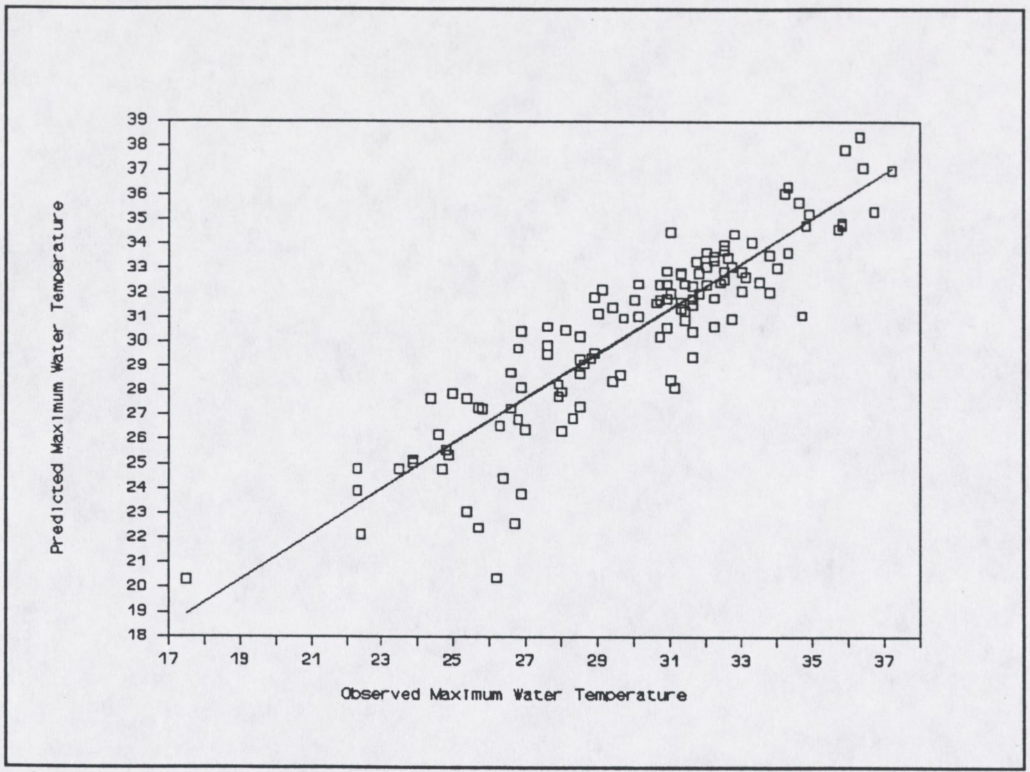


Figure G3. Relationship between predicted and observed maximum water temperature for the Shelton thermograph. (Y = 2.810621 + (X * 0.922017)) (R^2=.80685) (N = 124)

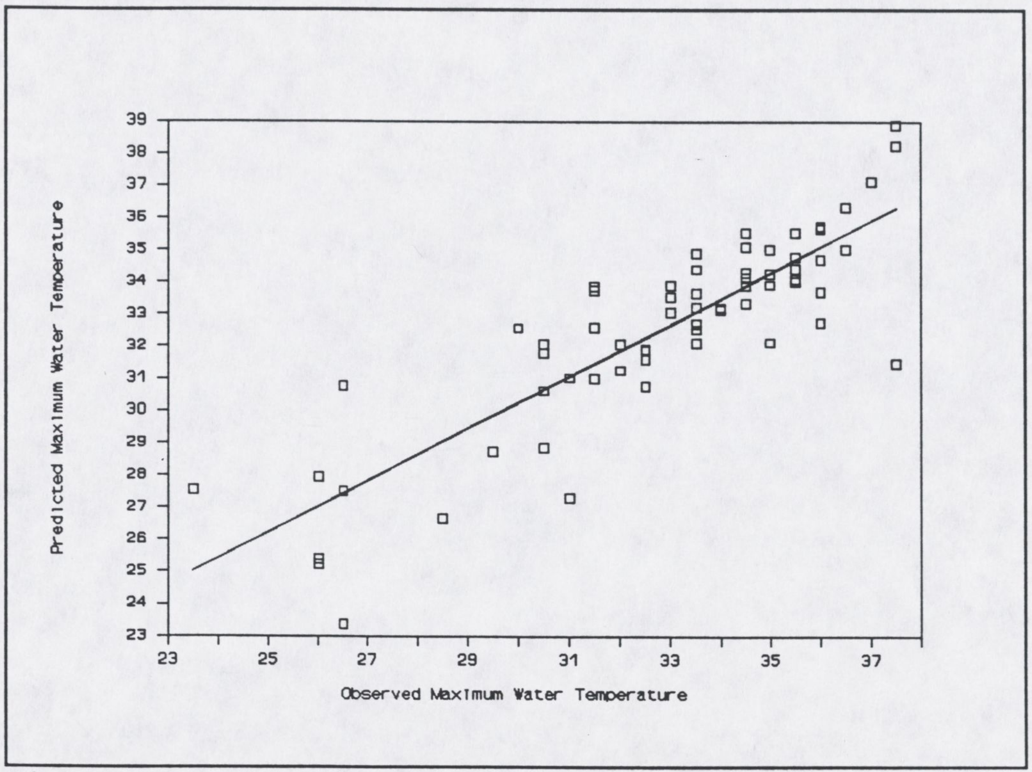


Figure G4. Relationship between predicted and observed maximum water temperature for the Mormon Island thermograph. (Y = 6.016277 + (X * 0.808041)) (R^2=.73488) (N = 64)

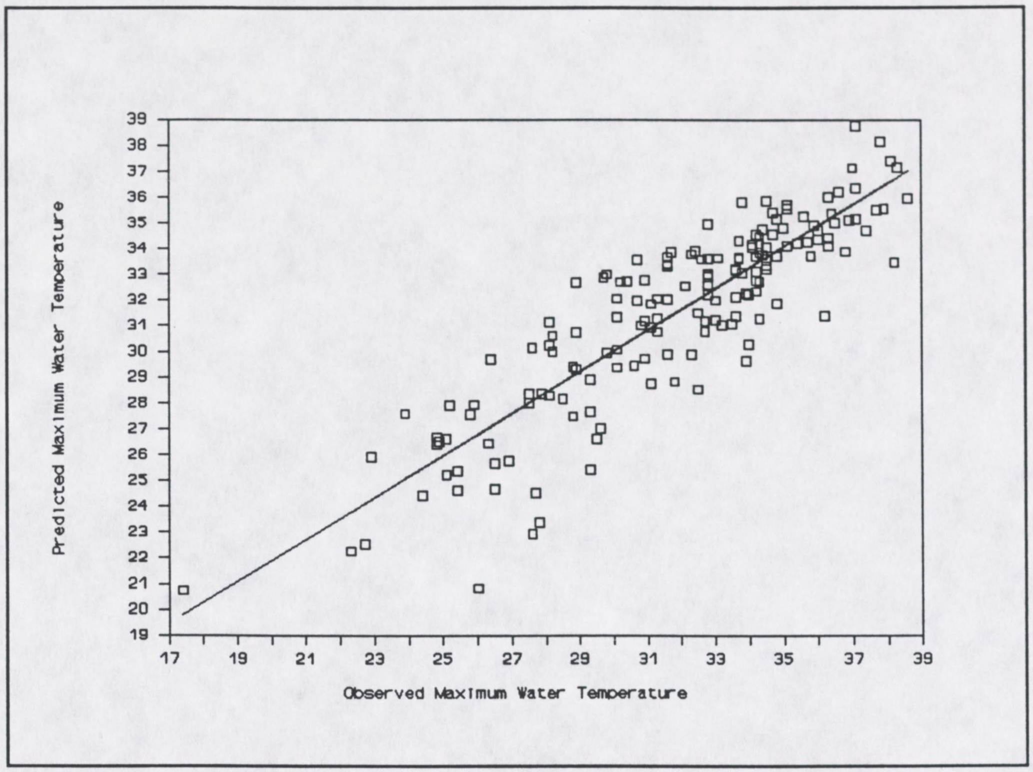


Figure G5. Relationship between predicted and observed maximum water temperature for the Phillips thermograph. (Y = 5.691637 + (X * 0.81161)) (R^2=.77423) (N = 163)

APPENDIX H

OBSERVED AND PREDICTED DAILY MEAN AND MAXIMUM WATER TEMPERATURES AT THE ODESSA AND MORMON ISLAND THERMOGRAPH FOR THE SUMMER OF 1988.

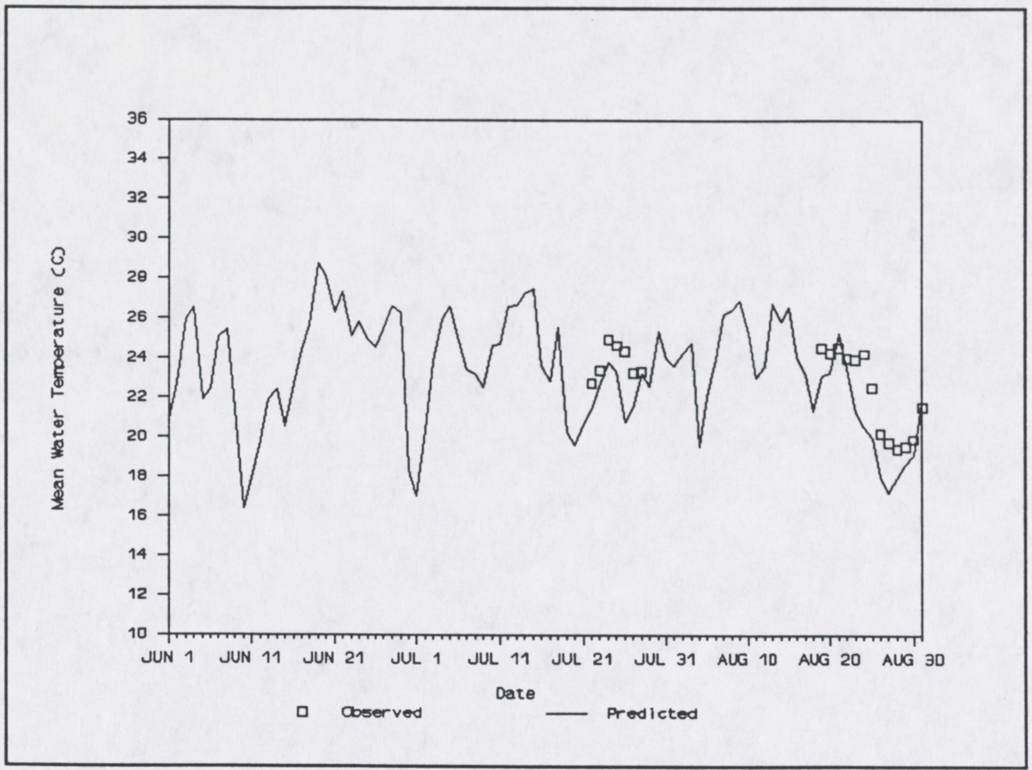


Figure H1. Results of validation run showing observed and predicted mean daily water temperature (°C) for the Odessa thermograph during the summer of 1988.

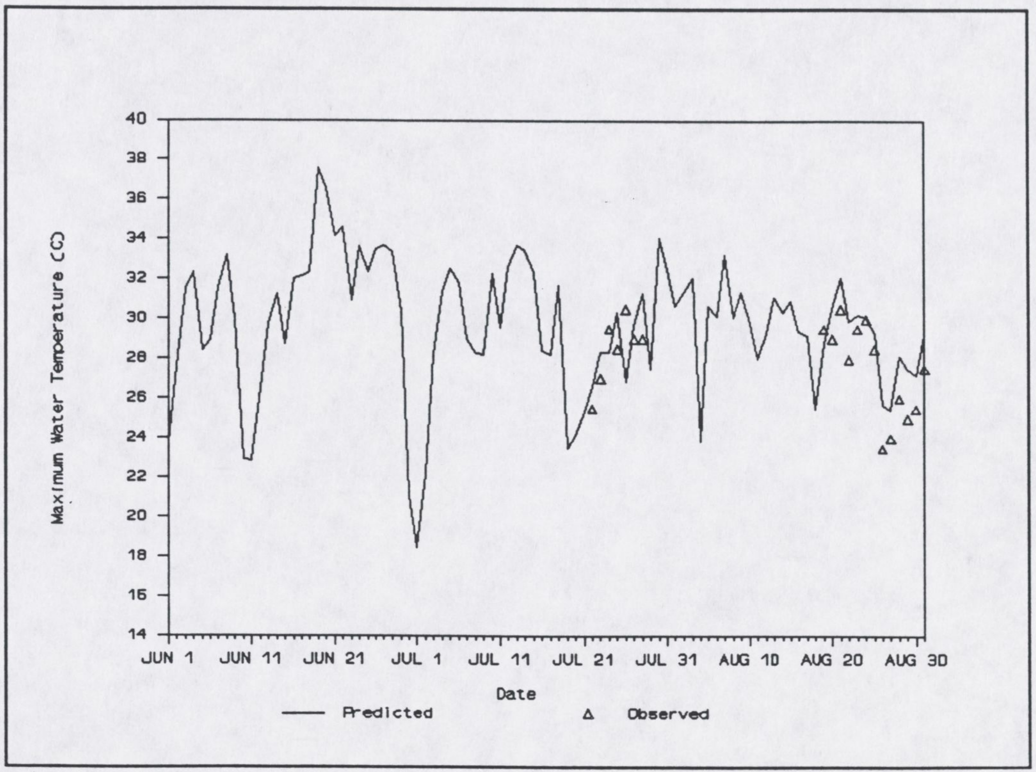


Figure H2. Results of validation run showing observed and predicted maximum daily water temperature (°C) for the Odessa thermograph during the summer of 1988.

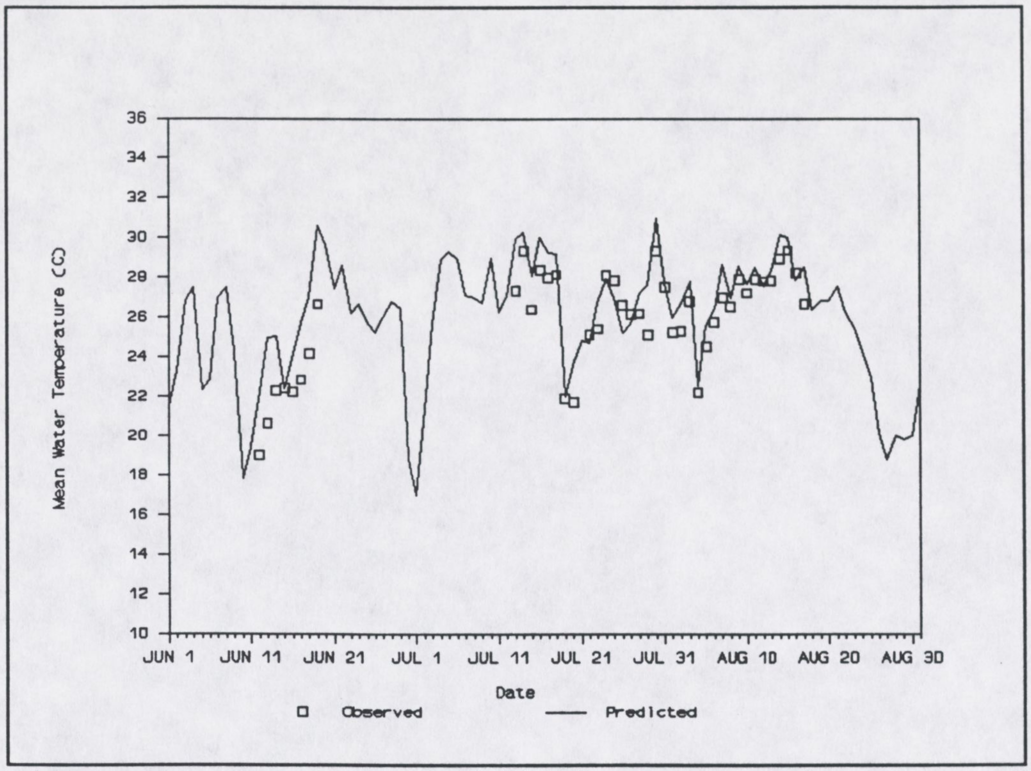


Figure H3. Results of validation run showing observed and predicted mean daily water temperature (°C) for the Mormon Island thermograph during the summer of 1988.

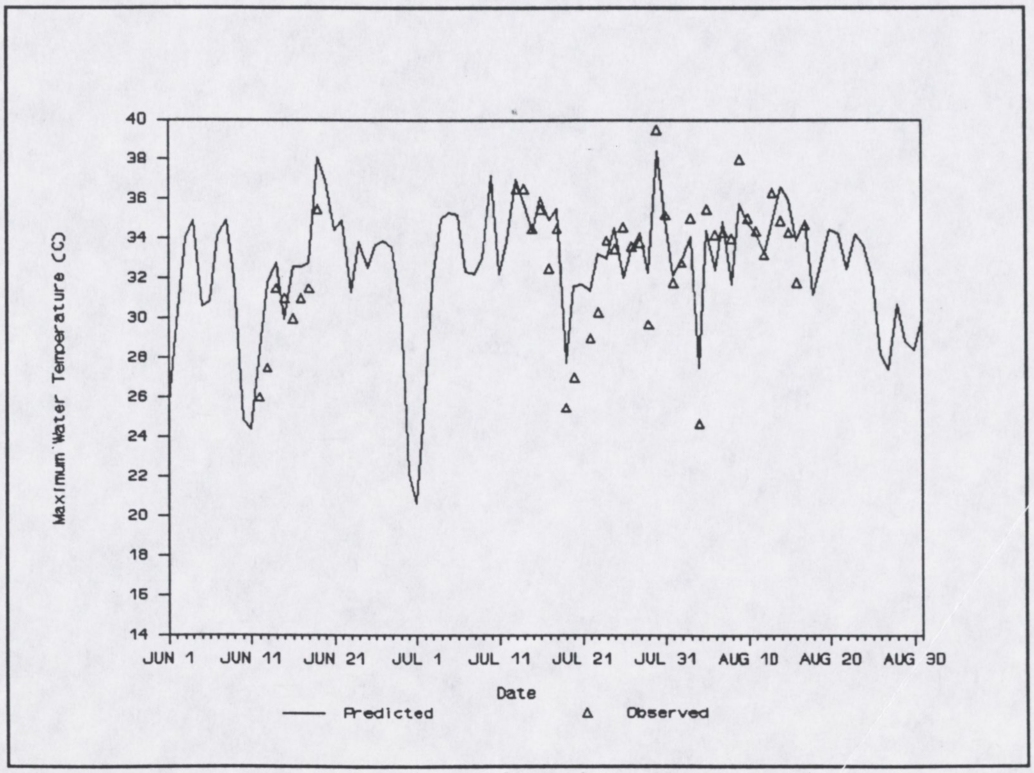


Figure H4. Results of validation run showing observed and predicted maximum daily water temperature (°C) for the Mormon Island thermograph during the summer of 1988.

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Uncertainty and Instream Flow Standards

By Daniel T. Castleberry, Joseph J. Cech Jr., Don C. Erman, David Hankin, Michael Healey, G. Mathias Kondolf, Marc Mangel, Michael Mohr, Peter B. Moyle, Jennifer Nielsen, Terence P. Speed, and John G. Williams

Several years ago, *Science* published an important essay (Ludwig et al. 1993) on the need to confront the scientific uncertainty associated with managing natural resources. The essay did not discuss instream flow standards explicitly, but its arguments apply. At an April 1995 workshop in Davis, California, all 12 participants agreed that currently no scientifically defensible method exists for defining the instream flows needed to protect particular species of fish or aquatic ecosystems (Williams, in press). We also agreed that acknowledging this fact is an essential step in dealing rationally and effectively with the problem.

Practical necessity and the protection of fishery resources require that new instream flow standards be established and that existing standards be revised. However, if standards cannot be defined scientifically, how can this be done? We join others in recommending the approach of *adaptive management*. Applied to instream flow standards, this approach involves at least three elements.

First, conservative (i.e., protective) interim standards should be set based on whatever information is available but with explicit recognition of its deficiencies. The standards should prescribe a reasonable annual hydrograph as well as minimum flows. Such standards should try to satisfy the objective of conserving the fishery resource, the first principle of adaptive management (Lee and Lawrence 1986).

Second, a monitoring program should be established and should be of adequate quality to permit the interim standards to serve as experiments. Active manipulation of flows, including temporary imposition of flows expected to be harmful, may be necessary for the same purpose. This element embodies the adaptive management principles that management programs should be experiments and that information should both motivate and result from management action. Often, it also will be necessary to fund ancillary scientific work to allow more robust interpretation of the monitoring results.

Third, an effective procedure must be established whereby the interim standards can be revised in light of new information. Interim commitments of water that are in practice irrevocable must be avoided.

The details of the monitoring program should vary from case to case. Where protection of particular populations is emphasized, the monitoring program should produce estimates of population size. However, population estimates by themselves often will not provide useful guides to action. This is particularly likely with anadromous fishes such as salmon, where populations of adults depend on harvest, ocean conditions, and other factors not related to instream flows, and populations of juveniles are hard to estimate accurately. Managers will learn more if the monitoring program also includes a suite of indices of the growth, condition, and development of the target species. These indices need to be interpreted with awareness of the complications arising from variations in life history patterns within and among populations. However, the indices and population estimates together will offer the best evidence of the mechanisms by which flows affect the survival and reproduction of individuals and thus the persistence of populations.

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The 1990 "Hodge Decision" in the case of *Environmental Defense Fund v East Bay Municipal Utility District* [Superior Court of Alameda County (California) No. 425955], with which several of us have been involved, exemplifies this approach. Judge Richard Hodge set flow standards for the American River, a major tributary to the Sacramento, that are intended to protect chinook salmon and other public trust resources from diversions by the East Bay Municipal Utility District. However, Hodge recognized the "fundamental inadequacy" of existing information regarding flow needs, so he retained jurisdiction and ordered parties to the litigation to cooperate in studies intended to clarify what the flow standards should be. Experience with these studies motivated the April 1995 workshop.

Our claim that there is now no scientifically defensible method for defining flow standards implies that the Physical Habitat Simulation Model (PHABSIM), the heart of the Instream Flow Incremental Methodology (IFIM), is not such a method. We have divergent views on PHABSIM. Some of us think that, with modification and careful use, it might produce useful information. Others think it should simply be abandoned. However, we agree that those who would use PHABSIM, or some modification of it, must take into account the following problems: (1) sampling and measurement problems associated with representing a river reach with selected transects and with the hydraulic and substrate data collected at the transects; (2) sampling and measurement problems associated with developing the suitability curves; and (3) problems with assigning biological meaning to weighted usable area (WUA), the statistic estimated by PHABSIM. Estimates of WUA should not be presented without confidence intervals, which can be developed by bootstrap methods (Efron and Tibshirani 1991; Williams 1996). Nor should any analytic method become a substitute for common sense, critical thinking about stream ecology, or careful evaluation of the consequences of flow modification, as has sometimes happened with the implementation of the IFIM.

Establishing instream flows involves both policy and science, and scientists and resource managers have challenging roles in the process. Managers need to accept the existing uncertainty regarding instream flow needs and make decisions that will both protect instream resources and allow development of knowledge that will reduce the uncertainty. Scientists need to develop and implement monitoring methods that will realize the potential of adaptive management, and develop the basic biological knowledge that will provide a more secure foundation for decisions that must balance instream and consumptive uses of water.

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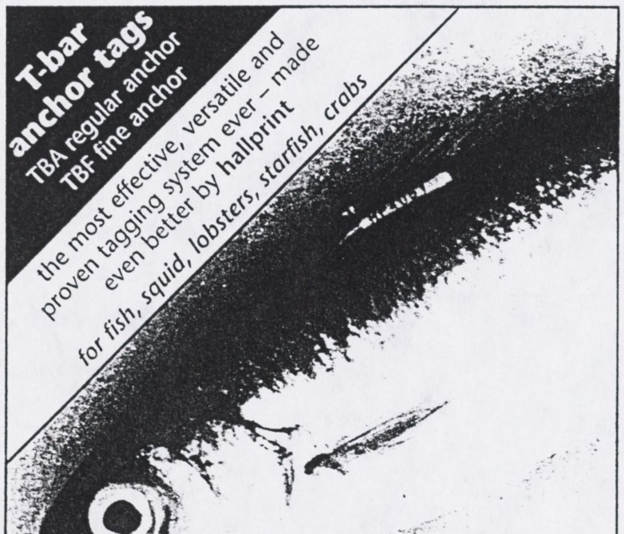

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