Managing a Trout Tailwater in the Presence of a Warmwater Endangered Species

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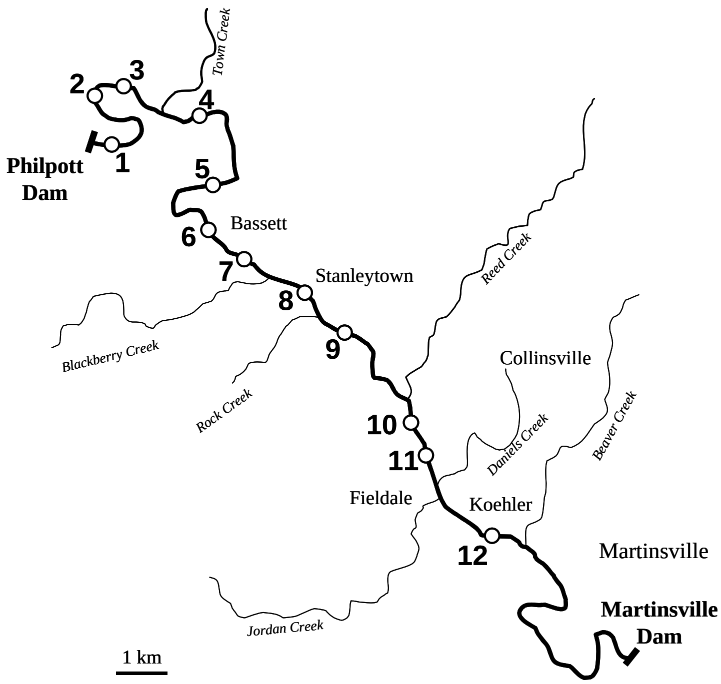
ABSTRACT— Flow and temperature in the Smith River tailwater (southwest Virginia) are influenced by a hydropeaking operation. Hypolimnetic releases support a naturalized brown trout (*Salmo trutta*) fishery and spatially restrict the endemic warmwater ichthyofauna. With trophy trout currently lacking, managers and anglers desire flow and temperature changes to enhance brown trout size and growth. However, management must also protect the endemic warmwater species, including the endangered Roanoke logperch (*Percina rex*). Dynamic flow and water temperature models were used to predict thermal habitat under alternative flow scenarios. Model output and species thermal criteria enabled assessment of potential benefit or detriment to brown trout and warmwater species. Currently the average release temperature (8°C) is below the optimal brown trout growth range (12-19°C). A 12°C outflow scenario predicted the greatest increase of optimal growth temperatures. Warmer temperatures also increase the area of suitable thermal habitat for warmwater species, including the Roanoke logperch. With changes in flow management we found it is possible to improve the trout fishery without detrimental effects to the warmwater community.

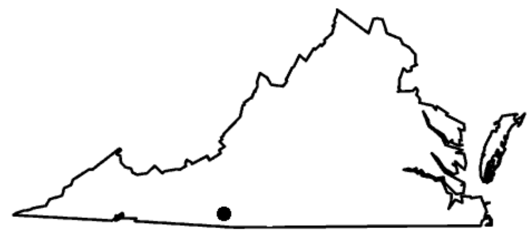
INTRODUCTION

Hydroelectric impoundments significantly alter the physical and biotic characteristics of the lotic system they control (Cushman 1985; Bain et al. 1988; Allan 1995). The physical effects of hydropeaking often include altered flow and temperature regimes, scouring, and channel and bank erosion (Bain et al. 1988; Allan 1995). Regulation subsequently affects the biota of the aquatic system both physiologically, and in terms of patterns in species assemblage (Bain et al. 1988; Kinsolving and Bain 1993; Allan 1995; Hunter 2003). However, the tailwaters below hydropeaking facilities have proven to provide economically valuable coldwater sport fisheries in geographic locations that could not otherwise support such species (Krause et al. in press).

The thermal characteristics of aquatic ecosystems hold great importance as to the distribution and vitality of ichthyofauna. Temperature is considered a controlling factor in the metabolism of fish, directly affecting physiological rates and efficiencies (Fry 1971; Ojanguren et al. 2001). Hinz et al. (1998) indicate that the thermal regime significantly contributes to growth variations spatially within a system. The process of seeking optimal temperatures in order to regulate metabolic expenditures is an important aspect of life-history in many fish (Hall 1972). Longitudinal differences in stream fish distribution are often a result of the independent responses of species to physiochemical gradients, rather than biotic interactions (Moyle and Li 1979; Matthews and Styron 1981). For this reason, temperature has been viewed as both a resource and a habitat among stream fishes (Magnuson et al. 1979; Ojanguren et al. 2000; Wehrly et al. 2003).

The Smith River is a sixth order tributary of the Dan River located in southwestern Virginia (Figure 1). In 1952, the U.S. Army Corps of Engineers impounded a section of the Smith River with the construction Philpott Dam, resulting in the creation Lake Philpott and the tailwater section of the Smith River. Philpott Dam generates peaking releases year-round, with generation schedules determined by energy demands and water availability. Due to peaking releases, flows fluctuate daily, excluding weekends, between 1.3 cms to 36.6 cms. The temperatures of peaking releases average 8°C, and increase with distance from the dam (Krause 2002). Due to peak flows, temperatures fluctuate hourly, declining up to 10°C in an hour during summer months (Krause 2002). The Smith River tailwater is home to an economically valuable, naturalized population of brown trout (*Salmo trutta*), stocked rainbow trout (*Oncorhynchus mykiss*), as well 33 nongame fish species, including the endangered Roanoke logperch (*Percina rex*). The tailwater, once a trophy brown trout fishery, now produces few trout that exceed 406mm (0.63kg) (Hartwig 1998; Orth et al. 2001; 2002; 2003; Hunter 2003).





Site #	Km below Dam	Section
1	0.5	
2	3.4	Upper
3	4.2	
4	6.2	Trophy
5	8.9	
6	11.9	
7	13.1	
8	14.9	
9	16.5	Lower
10	19.5	
11	20.6	
12	23.7	

Figure 1. Fish sampling sites, which also correspond to temperature model output locations, are numbered upstream to downstream in the Smith River tailwater, southwestern Virginia.

The Roanoke logperch, a large darter, is a noteworthy constituent of the Smith River's nongame fish assemblage due to its rarity. Characteristic of other species in the genus *Percina* , the Roanoke logperch is known to feed primarily on benthic and drifting invertebrates (Jenkins and Burkhead 1993). Rosenberger (2002) concluded that Roanoke logperch are extremely vulnerable to habitat degradation. The Roanoke logperch has a very small total range, and low population densities, occupying several warmwater streams in the Roanoke, Chowan, and Smith River drainages in Virginia (Jenkins and Burkhead 1993). In the Smith River drainage, small populations of Roanoke logperch are found above Philpott Dam, in the lower reaches of the tailwater, as well as in one of the primary tributaries, Town Creek, located approximately 5 km below the dam. Jenkins and Burkhead (1993) state that the Town Creek population is thermally isolated from the population that inhabits the tailwater further from the dam.

We hypothesize that water temperatures in the tailwater, a function of hydropeaking operations, may be limiting trout growth, as well as spatially restricting the distribution of the endangered Roanoke logperch. In this study, we modeled alternative flow scenarios for the Smith River tailwater to determine if there is a temperature regimen that can enhance the growth of brown trout, as well as increase thermal habitat for Roanoke logperch, and similar warmwater species.

METHODS

Flow and Temperature Model Development

The influence of alternative flow scenarios released from Philpott dam on water temperature were compared to the baseline flow regime released by the U.S. Army Corps of Engineers (USACE). Hourly flow and temperature was predicted with the dynamic ADYN and RQUAL river modeling system (Hauser and Walters 1995). Flow scenarios were modeled by season (Spring: Mar, Apr, May and Summer: Jun, Jul, Aug) under representative conditions calculated for lateral inflows, lateral inflow temperature, meteorological parameters, and starting water temperature at the upstream modeled end. Spring and summer seasons were chosen for further analysis because of their biological interest in terms of spawning activity and growth patterns. Hourly model output at 12 locations below Philpott dam which correspond to fish sampling sites of a Smith River brown trout study were assessed together as a tailwater, as well as within the upper (0.0-5.3 km), trophy trout managed (5.3-10.0 km), and lower (10.0-24.3 km) reaches (Orth et al. 2003) (Figure 1). Because the representative conditions did not change between the baseline and alternative scenario model runs, comparisons assess changes resulting from an alternative scenario. Alternative scenarios were evaluated for ability to increase occurrence of brown trout optimal growth temperatures (12-19°C), prevent exceedance of 21°C (brown trout maximum), maintain diurnal flux, and reduce maximum hourly temperature declines (MHTD). Detailed methods for model parameter data collection, input file development, calibration, predictive ability, and validation can be found in Krause (2002).

The baseline flow regime was determined using 13 years (1991-2003) of discharge data (USGS 2004). Histograms were used to determine occurrence frequency of typical conditions for baseflow discharge; drawdown discharge prior to peaking flow; and time-of-day of peaking flow. The typical magnitude and duration of peakflows were determined as the average of what occurred. The combination of these variables enabled the development of a representative baseline flow regime released by the USACE each season.

Lateral inflows were calculated for three sections of the tailwater and the Town Creek tributary (Krause 2002). The difference in flow between multiple gages estimated lateral inflows. Seven years of hourly data for cloudiness, dry bulb temperature, dew point, barometric pressure, and wind speed were obtained from the National Climatic Data Center (NCDC 2004) and solar radiation data from the Cooperative Networks for Renewable Resource Measurements (CONFRRM 2004). Representative meteorological parameters were generated as an average across years (1997-2003) within a season (spring and summer) for each of the 24 hours in a day. Water temperature was recorded by data loggers (Krause 2002). The upstream-most logger provided temperatures to initiate the RQUAL model and loggers in tributaries provided lateral inflow temperature data. Mean annual air temperature was also used for lateral inflow temperature depending on season (Krause 2002). Additional temperature loggers were used for model calibration and validation. The average of hourly temperature logger data across years (1999-2003) within a season for each of the 24 hours in a day provided representative conditions.

Three alternative flow scenarios were developed based on two potential modifications to Philpott dam; a depth variable intake allowing selective water temperature release or replacement of the 1950's era turbines with modern turbines. The *12°C outflow scenario* assumes 12°C water within the reservoir is released using the baseline flow regime to achieve temperatures within the reported brown trout optimal growth range (12-19°C) (Table 1) (Raleigh et al. 1986; Smith 1994; Ojanguren 2001). The *new turbines scenario* cuts the baseline peakflow magnitude in half and doubles the duration of the peakflow release. The *steady baseflow scenario* releases a constant non-peaking flow. This scenario releases a discharge 3.7 to 7.3 times greater (depending on season) than is presently released in order to account for the average seasonal inflow into the reservoir. This increase in baseflow is within the recommend range to maximize available habitat for all life stages of brown trout in the Smith River (USFWS 1986).

Table 1. Characteristics of the baseline and alternative flow scenarios. The peakflow, release duration, and release time were not applicable (NA) to the steady baseflow scenario.

Season	Scenario	Peakflow (m^3/s)	Baseflow (m^3/s)	Release Duration (hrs)	Release Time	Outflow Temp. (°C)
Spring	Baseline	31.3	1.4	6	7:00	7
	12°C Outflow	31.3	1.4	6	7:00	12
	New Turbines	15.6	1.4	12	7:00	7
	Steady Baseflow	NA	10.2	NA	NA	7
Summer	Baseline	31.8	1.5	5	14:00	9
	12°C Outflow	31.8	1.5	5	14:00	12
	New Turbines	15.9	1.5	10	14:00	9
	Steady Baseflow	NA	5.5	NA	NA	9

Thermal Preferences of the Roanoke logperch

We reviewed literature to determine the extent of knowledge concerning thermal preferences of the Roanoke logperch (*Percina rex*), as well as related species (i.e. *Percina caprodes*, *Percina burtoni*). In addition, we contacted several investigators familiar with the life history of the Roanoke logperch.

Roanoke logperch were collected and identified during one week in June (summer) over a three-year period (2000, 2001, and 2002) and one week in April (spring) over a two-year period (2001, 2002) in the Smith River tailwater. Fish were collected at 12 study sites representing the longitudinal gradient of the tailwater (Figure 1). Sampling was performed via electrofishing a 100m blocked section with a three-pass depletion method. Using the temperature modeling methodology described above, temperatures were modeled for each of the 12 sampling sites in the tailwater for the month of April during the years 2001 and 2002 and during the month of June in the years 2000, 2001, and 2002.

A presence-absence matrix was developed to determine at which study sites Roanoke logperch were present or absent during each sampling event. A monthly average water temperature was computed for each of the twelve sites during the month the sampling occurred. To derive a lower thermal threshold for presence, the lowest average temperature at sites where logperch were present was computed for all years during the two seasons sampled.

RESULTS

Temperature Predictions under Baseline and Alternative Scenarios

The 12°C outflow scenario provided the greatest increase in occurrence of 12-19°C temperatures during spring and summer by 50% and 25% over baseline conditions throughout the tailwater, respectively (Table 2). The improvement in water temperature from the 12°C outflow scenario was greatest in the upper section (0.0-5.3 km) of the tailwater (Figure 2), where occurrence of 12-19°C temperatures increased from 0% to 60% in spring, and 9% to 100% in summer (Table 2). Scenarios involving modern turbines (the new turbine and steady baseflow scenario) caused little to no improvement of optimal growth temperatures (Table 2). None of the scenarios caused water temperature to exceed the Department of Environmental Quality maximum 21°C standard during any season, with the exception of the 12°C outflow scenario, which only caused a 1% exceedance in the lower section (10.0-24.3 km) during summer (Table 2). During summer, the steady baseflow scenario caused the largest decline (up to 3°C) in diurnal flux (Table 2). Minimal to no change occurred for spring. Hourly declines in temperature only exceeded the DEQ 2°C standard in summer and the steady baseflow scenario caused the greatest reduction of MHTD (1-4°C). The 12°C outflow scenario was the only scenario able to elevate the average temperature from baseline conditions during spring and summer (Table 2). The increase in average temperature was greatest in the upper section (Figure 2); 4°C increase in spring and 3°C in summer.

Table 2. Temperature predictions for baseline conditions and alternative scenarios shown as percent time temperature was within 12-19°C, percent time 19°C & 21°C was exceeded, diurnal flux (°C), maximum hourly temperature decline (MHTD °C), and average temperature (°C). Values are averages for a one week period (Tuesday-Monday) from 0.5 to 23.7 rkm below Philpott dam by season. In parenthesis are model predictions averaged within the upper, trophy trout managed, and lower section of the tailwater.

Season	Scenario	%12-19°C	% >19°C & <21°C	%>21°C	Diurnal Flux (°C)	MHTD (°C)	Avg. (°C)
Spring	Baseline	10 (0,7,15)	0 (0,0,0)	0 (0,0,0)	3 (3,4,3)	1 (0,1,2)	10 (8,10,11)
	12°C Outflow	60 (60,47,64)	0 (0,0,0)	0 (0,0,0)	3 (3,4,2)	0 (0,0,0)	12 (12,12,12)
	New Turbines	10 (0,7,15)	0 (0,0,0)	0 (0,0,0)	3 (2,3,2)	1 (0,1,1)	9 (7,9,10)
	Steady Baseflow	0 (0,0,0)	0 (0,0,0)	0 (0,0,0)	3 (2,3,3)	0 (0,0,0)	9 (7,8,9)
Summer	Baseline	55 (9,76,68)	14 (0,0,24)	0 (0,0,0)	6 (3,6,7)	3 (2,3,4)	14 (10,14,16)
	12°C Outflow	80 (100, 96,66)	20 (0,4,33)	0 (0,0,1)	5 (3,5,6)	2 (1,3,3)	16 (13,15,17)
	New Turbines	50 (10,63,64)	14 (0,0,25)	0 (0,0,0)	6 (3,7,7)	2 (1,3,2)	14 (10,13,16)
	Steady Baseflow	64 (4,40,97)	0 (0,0,0)	0 (0,0,0)	3 (2,4,3)	0 (1,1,0)	13 (10,12,15)

Thermal Habitat for Smith River Fish Species under Alternative Scenarios

Given Roanoke logperch presence-absence information, as well as average temperatures, a threshold temperature value for presence was determined for spring (10.73°C) and summer (14.34°C) seasons (Figure 2). During spring, the12°C outflow scenario provided substantial improvement, increasing the logperch's potential range to include the entire tailwater (Figure 3). During summer, the 12°C outflow scenario predicts the greatest potential increase of logperch presence throughout the tailwater, by increasing water temperatures above the threshold value at 5 km rather than 10 km (Figure 3).

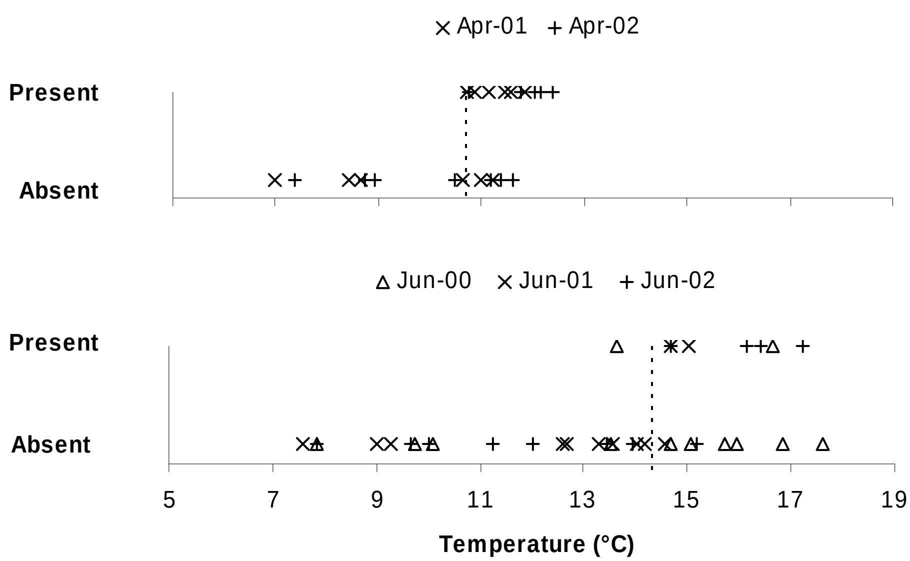


Figure 2. Presence-absence of Roanoke logperch along a temperature gradient for April (spring) and June (summer). The dashed line indicates the lower threshold temperature presence value. No sites were sampled at higher temperatures.

Assuming that the growth of brown trout in the Smith River tailwater would improve under an increased occurrence of optimal growth temperatures (12-19°C), only the 12°C outflow scenario provided improvement in all reaches during spring, and the dam reach in summer (Figure 3).

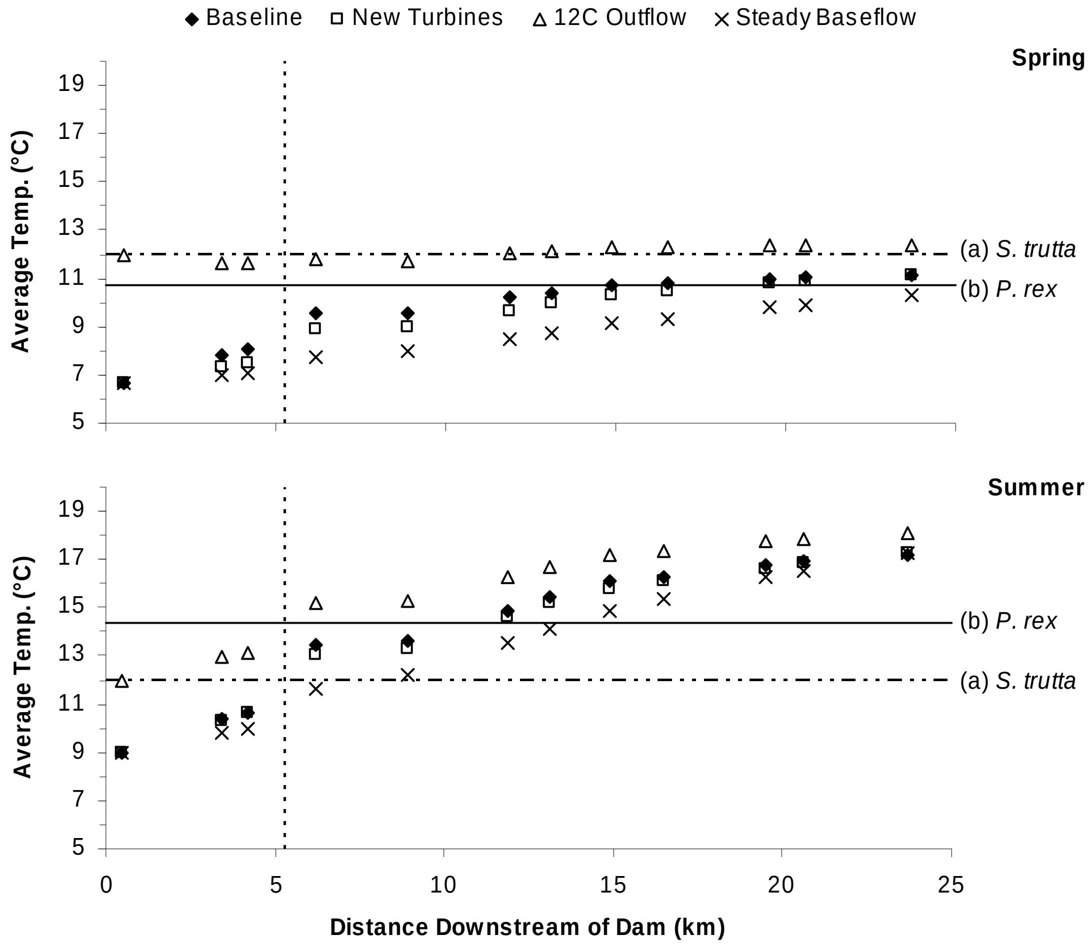


Figure 3. Spring and summer average temperature predicted under alternative flow scenarios in relation to distance downstream of Philpott Dam. Horizontal lines represent (a) the lowest optimal growth temperature for brown trout (*S. trutta*) and (b) the threshold temperature presence value for Roanoke logperch (*P. rex*). The vertical dashed line indicates the location of Town Creek.

Discussion

These results show that the effective management of trout and endemic warmwater species in hydropeaking tailwaters are not necessarily mutually exclusive. In addition, our study emphasizes the importance of deliberate, informed flow management to alter the ichthyofauna of tailwaters.

The Smith River is a tailwater fishery that holds possibilities for improvement. Many authors have emphasized the importance of water temperature upon growth and survival of fish (Fry 1971; Hinz 1998; Ojanguren 2001). Our study suggests that slightly altering the temperature of peaking releases may provide a greater physiological potential for growth among the naturalized brown trout. Additionally, this flow scenario requires no change in peaking operations, allowing the controlling agency to continue meeting hydroelectric energy demands (Krause et al. in press).

Water temperature also strongly influences the patterns of distribution of stream fishes (Matthews and Styron 1981; Matthews 1987; Hawkins et al. 1997). In addition to improving the conditions for trout growth, our predicted alternative flow scenario may also increase the habitable area of the tailwater for the endangered Roanoke logperch. Logperch have been observed to spawn during mid-April to early May in waters between 12 and 14°C (Burkhead 1983; Jenkins and

Burkhead 1993). Our results show that during April, a 12°C outflow scenario would permit suitable spawning temperatures to pervade the entire tailwater, thereby significantly increasing the chance of spawning success. This scenario may provide an additional benefit to the conservation of Roanoke logperch in the Smith River tailwater. Jenkins and Burkhead (1993) indicate that two populations of Roanoke logperch exist within the vicinity of the tailwater. One population occupies downstream reaches of the mainstem; the other inhabits Town Creek, thermally isolated from the mainstem population. Our 12°C outflow scenario predicts that temperatures would become suitable for Roanoke logperch upstream of Town Creek, allowing for the spatial connection of two previously isolated habitats.

Roanoke logperch are often classified as a warmwater stream fish (Burkhead 1983; Jenkins and Burkhead 1993; A. Rosenberger, University of Idaho, pers communication). Conditions that increase the potential range of the logperch may also increase the range of other warmwater nongame fish in the tailwater. Releasing the spatial restrictions of nongame fish imposed by the current temperature regimen may provide an indirect benefit to brown trout in the tailwater by increasing the forage available to them.

We assume that increased water temperatures result in increased trout growth. Continuing studies on the Smith River tailwater using bioenergetics modeling and *in situ* sampling will determine whether increased temperatures do in fact enhance trout growth. Additionally, we concede that the life history and true temperature preferences of the Roanoke logperch are not yet well known (especially summer optimum). Due to small populations and low densities, our data on logperch are limited. Finally, realistic changes in flow management to enhance both the economic and ecological integrity of the tailwater require a significant initial investment of time and resources, and the cooperation of agencies.

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