PASSAGE OF NORTH TEMPERATE FISH

THROUGH THE

COWAN DAM DENIL FISHWAY

BY

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ABSTRACT

Fish passage through a standard Denil fishway under low tailwater conditions was studied at Cowan Dam in west-central Saskatchewan in 1990. In 1991 and 1992, fish passage through an experimental two-level Denil fishway was studied at the same location under similar flow conditions. Six species of fish utilized the Cowan Dam Denil fishway in 1990; northern pike, walleye, white suckers, longnose suckers, cisco and lake whitefish. Tag returns suggest that most fish that congregate below Cowan Dam in the spring originate in Lac Ile-a-la-Crosse 150 to 200 km downstream.

Northern pike waited until spawning had been completed before ascending the fishway. Only 12.1% of pike congregated below the dam are estimated to have ascended the fishway. During both 1990 and 1991, the number of pike ascending the fishway appeared to decline as water velocities in the standard and the two-level Denil fishways increased. Mean pike length also declined over the period of fish movement, and as water velocities in the standard Denil declined. Walleye did not appear to have any difficulty ascending the standard Denil fishway in 1990, however they did appear to have difficulty ascending the two-level Denil in 1991. Only 29% of white suckers that ascended the fishway did so prior to spawning. According to recaptures of tagged fish, 58.8% of white suckers present in the tailwater pool ascended the standard Denil fishway in 1990. White suckers also appeared to be able to ascend the two-level Denil without difficulty. Ninety-eight percent of longnose suckers ascended the fishway prior to spawning in 1990. Longnose suckers appeared to ascend both the standard and two-level Denil fishways without obvious delay or difficulty. Only small numbers of cisco and lake whitefish utilized the standard Denil fishway in 1990.

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INTRODUCTION

GENERAL

Many freshwater fish species undertake migrations to reach suitable spawning sites, productive feeding areas, or areas of favourable water quality. North temperate fish species known to undertake extended spawning migrations include northern pike (*Esox lucius*), walleye (*Stizostedion vitreum*), white sucker (*Catostomus commersoni*) and longnose sucker (*Catostomus catostomus*).

Fish migrations can be disrupted or blocked by natural obstructions such as rock slides, water falls and beaver dams, or by man-made obstructions such as water control weirs or dams. Where such obstructions occur, fishways are often installed to allow fish to complete their migrations. Fishways are hydraulic structures that enable fish to swim upstream, through or around an obstruction, under their own effort (Clay 1961).

The passage of anadromous species through fishways has been studied extensively, however, the passage of migrating north-temperate freshwater fish has received less attention. Of approximately twenty-five Alberta, eight Manitoba and seven Saskatchewan fishways, less than half have been studied to determine whether they pass local fish species effectively (Appendix 1). Many of the studies which have been done were of limited duration and scope.

The Cowan Dam Denil fishway was studied briefly in 1985 (Katopodis *et al.* 1991). Due to high tailwater levels that year, it was only necessary to operate the single uppermost fishway chute to facilitate fish passage.

STUDY OBJECTIVES

The following study examined fish passage at Cowan Dam through a standard Denil fishway in 1990 under low tailwater conditions, and through a two-level Denil fishway in 1991 and 1992 under similar flow conditions. Specific objectives of the 1990 study were to:

1. identify the population characteristics of fish species utilizing the fishway.
2. describe temporal changes in spawning condition of fish using the fishway.
3. examine why different species are motivated to ascend the fishway.
4. determine if the fishway selected for passage of fish based on physical characteristics, such as length, sex, and species.
5. determine where migrating fish originate in the watershed.
6. estimate the efficiency of the fishway for passing different fish species.
7. relate fish passage to flow conditions in the fishway.

Study objectives in 1991 and 1992 were to:

1. determine whether a two-level Denil fishway would successfully pass fish.
2. determine whether both levels of the two-level Denil were equally effective in passing fish.

BACKGROUND

LOCAL MIGRATING SPECIES

Northern pike

Pike prefer clear, warm, slow, meandering, heavily vegetated rivers, or warm weedy bays of lakes. In some locations, pike make extensive spawning migrations in April or early May, although many remain in lakes and spawn in flooded vegetation along the lake margins. Preferred spawning temperatures are between 8.0°C and 12°C (Inskip 1982).

Spawning occurs during the daylight hours in shallow water over flooded grasses and other vegetation along the shores of rivers, lakes, and marshes. An individual female may spawn from 5 to 60 eggs at each spawning act, and repeat this many times a day for two to five days (Koshinsky 1979). The adhesive eggs sink to the bottom and adhere to the vegetation at the spawning site. In one to three weeks, depending on incubation temperatures, the eggs hatch. Fry usually attach to vegetation for a few days while resorbing their yolk sac, and then become free swimming (Howard and Thomas 1970). They typically remain in the shallow spawning areas for a number of weeks. Mortalities of eggs and young due to predation, or by stranding due to receding water levels, have been estimated to be as high as 99.9% (Johnson and Moyle 1969; Scott and Crossman 1973).

Females tend to grow faster, attain a larger size, and live longer than males. In southern Canada, females mature at three to four years of age, and males at two to three years (Scott and Crossman 1973). Pike prey mostly on smaller fish, however they are quite opportunistic and will feed on whatever food is most readily available (Lawler 1965).

Walleye

In Saskatchewan, walleye spawn in April or May when the water temperature rises to between 6°C and 11°C. Fish move into tributary rivers as soon as they are free of ice; often well before the lake ice disappears. Males usually arrive on the spawning grounds first and often outnumber females by ratios of 5:1 or greater (Rawson 1957; Bodaly 1980). Upstream migration and spawning reportedly occurs at night. Preferred spawning areas contain a mixture of gravel, cobble and small boulders. In streams, spawning areas are optimally located over suitable substrate at depths of 40 to 80 cm, and exposed to water velocities of 0.3 to 1.0 metres per second (Liaw 1991). Eggs are broadcast and fall into crevices between the substrate of the spawning site where they incubate for about two weeks before hatching. Once hatched, walleye fry become free swimming and disperse about one month after spawning occurs.

Female walleye grow faster than do males from about age seven onward. Male and female walleye enter the spawning migration when they are about five years of age (Rawson 1957). Walleye prey primarily on smaller fish.

White sucker

White suckers usually inhabit warm shallow lakes, or bays and tributary rivers of large lakes. White suckers spawn in the spring in streams, and to a lesser degree along the shore of lakes, or at the mouths of blocked streams. Adults tend to home to a particular spawning stream (Olson and Scidmore 1963; Durbin and Fernet 1979). In a tributary of Jack Lake, Ontario, spawning migration began when stream temperatures were between 3°C and 10°C, but the main spawning migration did not occur until maximum daytime temperatures were between 12°C and 17°C (Corbett and Powles 1983). Geen *et al.* (1966) found that the majority of white suckers moved upstream between noon and midnight, with peak movement occurring during the evening.

Once water temperatures reach 10°C to 15°C, spawning usually takes place over a gravel bottom in water one metre deep or less (Geen *et al.* 1966; Corbett and Powles 1983). Reportedly, most spawning occurs at dawn and dusk (Scott and Crossman 1973), however, Corbett and Powles (1983) observed that white sucker spawning in a tributary stream of Jack Lake, Ontario did so only at night. The adhesive eggs are scattered over the stream bottom and hatch in about two weeks. The fry remain in the spawning gravel for an additional one to two weeks. Adults begin moving off the spawning grounds to return to the lake 10 to 14 days after spawning begins. The majority of females return downstream before most of the males (Geen *et al.* 1966). About one month after spawning, the fry leave the gravel and return downstream to their originating lake (Corbett and Powles 1983).

Growth in suckers is extremely variable from lake to lake, and may cease altogether after maturity is reached. Maximum age is reported to be about 17 years (Beamish 1973). Females tend to grow faster, become larger, and live longer than males. Age of maturity varies from three to five years, with males maturing a year earlier than females. They feed primarily on detritus and bottom dwelling organisms such as aquatic insect larvae and pupae, mollusks, and crustaceans (Brown and Graham 1954).

Longnose sucker

Longnose suckers prefer to spawn in streams, although they will spawn in the shallow areas of lakes. They enter spawning streams in the spring as soon as the water temperature reaches 5°C (Geen *et al.* 1966). The highest rate of movement during the spawning migration usually occurs between 11°C and 14.5 °C (Bailey 1969). Longnose suckers begin their spawning run and reach peak migration several days before that of white suckers in the same stream. Upstream movement occurs between noon and midnight with the greatest number moving in the evening. Marked increases in water temperature are associated with increased fish movement, while drops in temperature result in decreased movement (Brown and Graham 1954; Bailey 1969).

Spawning takes place in water 15 to 30 cm deep with a current of 30 to 45 cm per second. The adhesive eggs are scattered over a gravel substrate ranging in size from 0.5-10 cm in diameter. The spawning act occurs during the daytime, and lasts for three to five seconds, occurring as often as 6 to 40 times per hour (Geen *et al.* 1966). Females can lay between 17,000 and 60,000 eggs (Harris 1962). The spawning period is of relatively short duration, with some adults returning to the lake as early as five days after the run begins. Generally, the majority of females return to the lake prior to the males (Geen *et al.* 1966). The eggs adhere to the gravel substrate for about two weeks before hatching. The fry remain in the gravel for another one to two weeks absorbing their yolk sacs before emerging and moving downstream with the current (Scott and Crossman 1973).

Male and female longnose suckers grow at about the same rate, however, female longnose suckers live longer than males, and therefore attain a larger maximum size (Harris 1962). Being longer lived, females spawn more often and over a greater number of years than do males (Geen *et al.* 1966). Males are usually smaller and younger than females (Brown and Graham 1954; Geen *et al.* 1966; Bailey 1969) in the spawning population. First spawning is estimated to occur at five to seven years of age in southern populations (Geen *et al.* 1966), and nine years of age in northern ones (Harris 1962).

The food eaten by adult longnose suckers is highly variable, but consists mostly of invertebrates, such as amphipods, aquatic insect larvae and pupae, copepods, cladocerans, as well as algae and higher aquatic plants (Brown and Graham 1954; Barton 1980). The longnose sucker is not considered to be a serious egg predator of other fish (Scott and Crossman 1973).

Cisco

Cisco (*Coregonus artedi*) spawn in October or November during times of declining water temperature, one or two weeks after lake whitefish spawn. Spawning usually takes place over a gravel or stony bottom, when water temperatures drop to between 5°C and 3°C (Scott and Crossman 1973).

Male and female cisco grow at about the same rate, although females attain a larger size as they live longer. Cisco usually mature at three or four years of age, and can live as long as 13 years in cold northern lakes. Cisco are considered to be primarily a lake species due to their pelagic nature. Colby and Brooke (1969) determined that the maximum sustained temperature tolerated by adult cisco was about 20°C, and as temperatures begin to warm in the spring or early summer, cisco generally migrate to deeper, cooler water.

Cisco consume zooplankton, crustaceans, insect larvae and water mites (Koshinsky 1965), and have been reported to eat the eggs and fry of other fish (Scott and Crossman 1973).

Lake whitefish

Lake whitefish (*Coregonus clupeaformis*) are a cool water species which usually resides in the deeper waters of lakes once the surface waters warm up in late spring or early summer. Lake whitefish spawn in October or November when water temperatures drop to between 8°C and 4°C (Scott and Crossman 1973). Spawning occurs in water less than 3.0 metres deep over boulder, rubble and sand substrates (Bidgood 1974). Male whitefish mature at a younger age than females, and tend to live longer (Scott and Crossman 1973).

Whitefish feed predominantly on zooplankton until they are three or four years of age. Adult whitefish switch to more benthic foods, including aquatic insect larvae and nymphs, crustaceans and small fish (Watson 1963; Koshinsky 1965). Fish eggs were also found seasonally in whitefish stomachs (Bidgood 1973; Scott and Crossman 1973).

FISHWAY DESIGN

Types of fishways

Fundamental to effective fishway design is the capacity to dissipate sufficient kinetic energy from the water flowing through the fishway, to enable fish to ascend with a minimum of stress (Clay 1961). Although there are many fishway designs, they can be divided into four major types: pool and weir, vertical slot, culvert and Denil fishways (Katopodis 1990a).

Pool and weir fishways are the oldest, and one of the most commonly used, types of fishways (Decker 1967; Rajaratnam *et al.* 1987a). Most fishways installed on the prairies prior to the mid-1970's were of this type. These fishways consist of a series of descending stepped pools each separated by a weir over which the water spills (Figure 1). Modern versions incorporate orifices at the base of each weir to enable weaker species that can not swim or jump over the weirs to ascend the fishway. Although relatively simple to design and

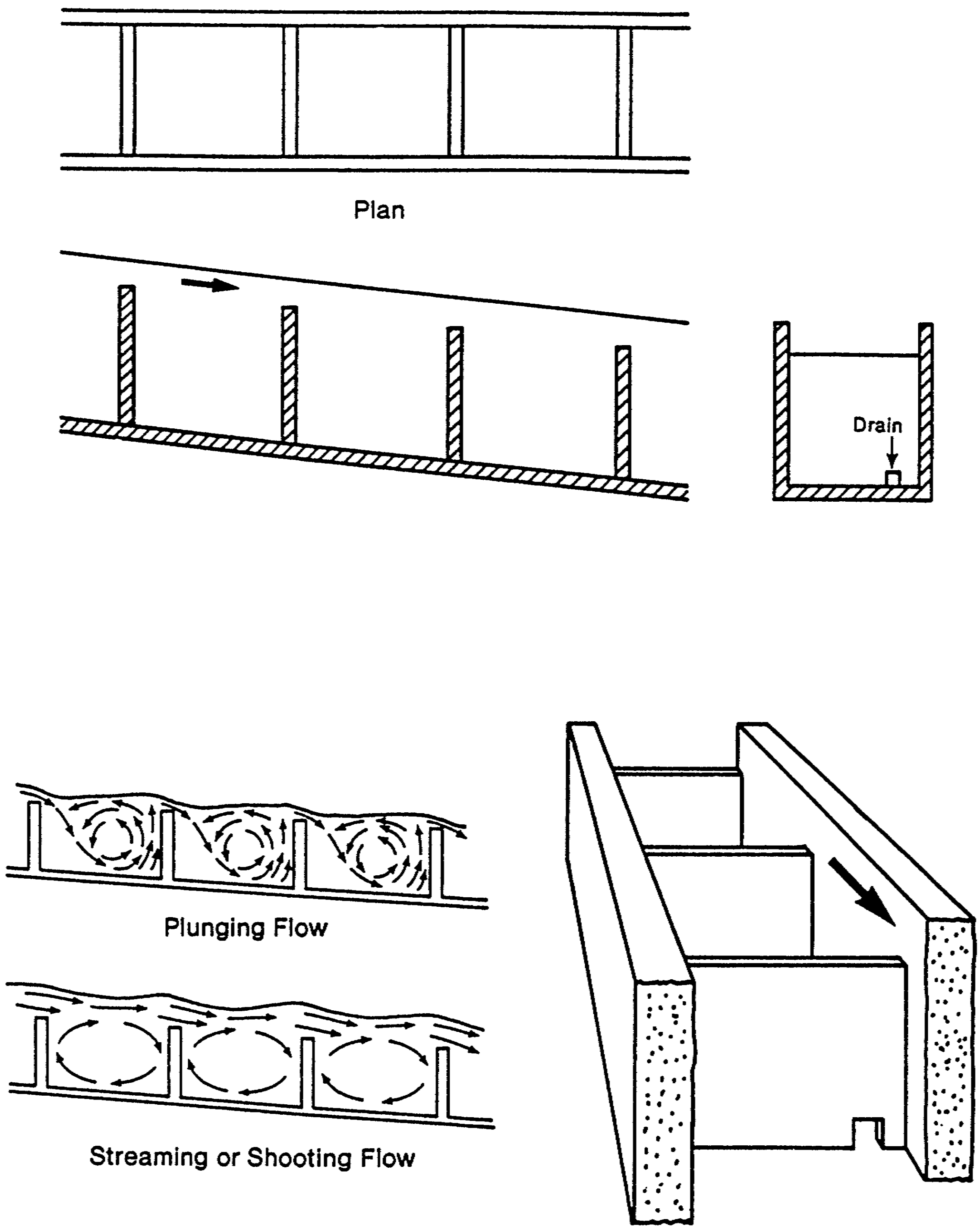


Figure 1. Pool and weir fishway (from Katopodis 1981).

build, pool and weir fishways are more sensitive to changes in upstream and downstream water levels than other types of fishways. If the range between levels is too great, hydraulic conditions in the fishway can change reducing or preventing fish passage (Decker 1967).

Vertical slot fishways consist of a descending chute equipped with vertical baffles spaced at regular intervals to create a series of pools (Figure 2). Because the volume of water passed is large, vertical slot fishways provide good entrance water attraction flows (Clay 1961; Decker 1967). Although usually more expensive than other types, vertical slot fishways are able to handle wide fluctuations in water levels without affecting their ability to pass fish. A number of vertical slot fishways were built on the prairies during the 1970's and early 1980's.

Culvert fishways are simply culverts with special baffles, blocks, or plates installed to reduce water velocities within the pipe. Culvert fishways are mainly associated with roadway construction, and have slopes of between 0.5% and 5.0%. Their main advantage is lower construction and maintenance costs than bridges (Katopodis 1990a).

Denil fishway - standard

Denil fishways were invented in Europe in 1908 by G. Denil (Clay 1961; Decker 1967). Denil fishways consist of a rectangular chute with closely spaced baffles along the sides and bottom projecting at right angles to the water flow (Figure 3). In a standard Denil fishway the baffles are set into the flow at a 45° angle, and function to turn the water back on itself to dissipate its energy (Katopodis and Rajaratnam 1983; Katopodis 1990b). In addition to effective energy dissipation, Denil fishways provide fish with a continuous and direct route

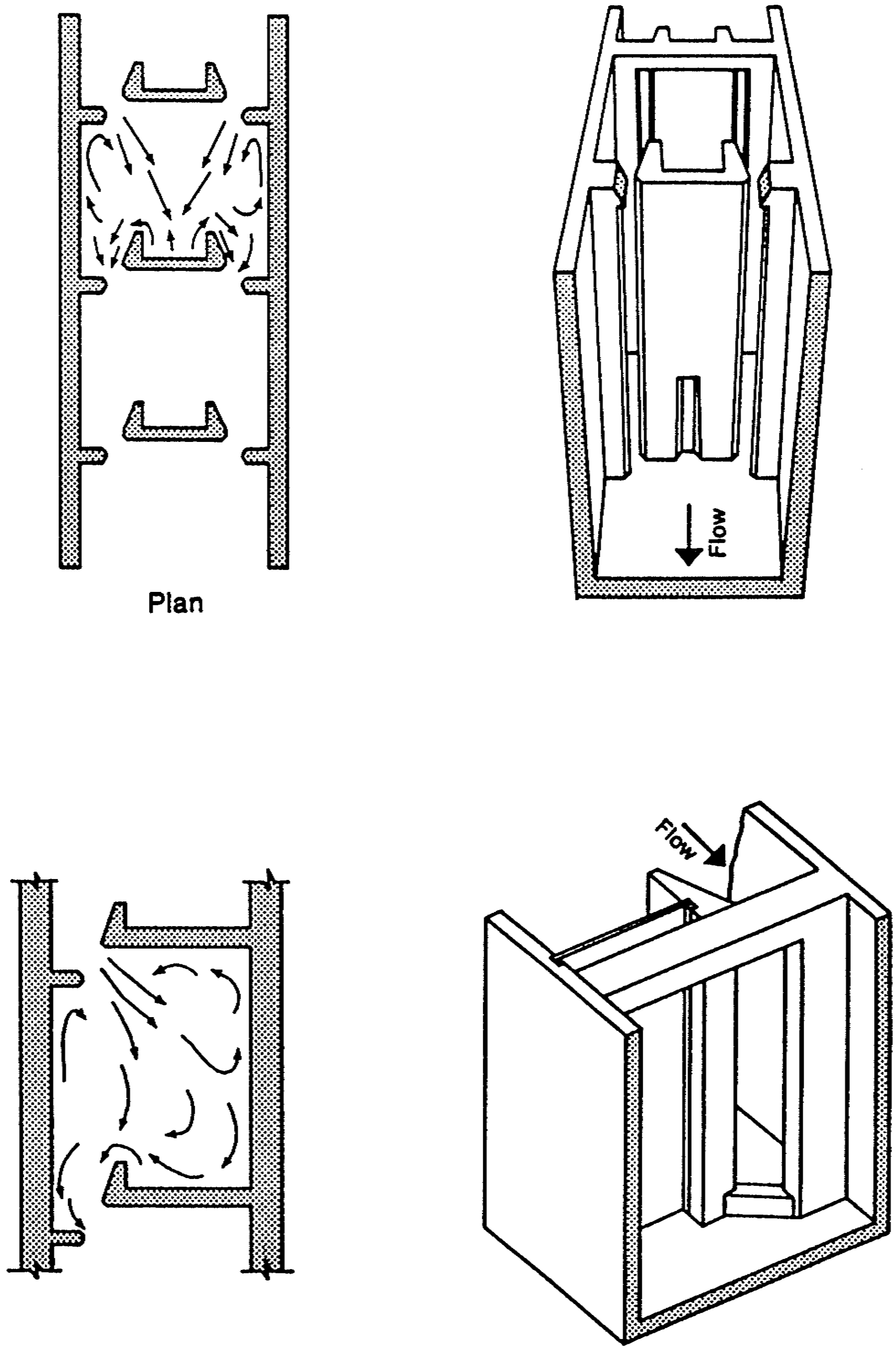


Figure 2. Double and single vertical slot fishways (from Clay 1961).

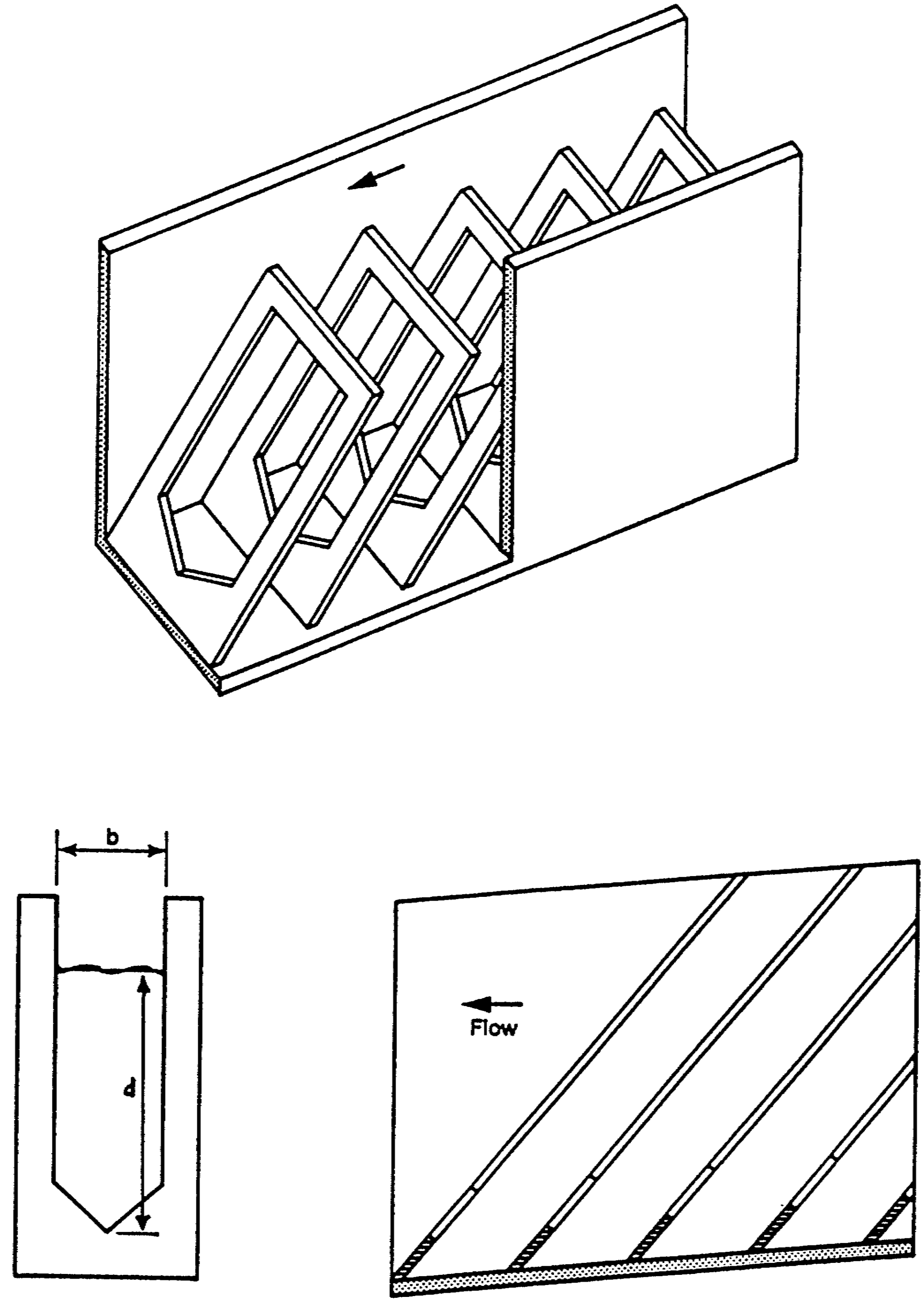


Figure 3. Standard Denil fishway (from Katopodis 1981).

of ascent (Katopodis 1981). Denil fishways also provide good attraction conditions at the fishway entrance due to the large volumes of water passed and fast velocities near the surface (Clay 1961; Katopodis 1990a). Most fishways installed in Alberta, Saskatchewan and Manitoba since about 1980 have been of this type, since they appear to pass freshwater fish species better than pool and weir fishways, and are less expensive to build than vertical slot types.

Water velocities in standard Denil fishways are lowest at the bottom of the flume and increase up to the water surface (Katopodis and Rajaratnam 1983). Fish which attempt to ascend the fishway near the bottom of the flume face the lowest water velocities, while those which attempt to swim near the surface face the highest velocities (two to three times that near the bottom). Since fish must constantly swim while in Denil fishway chutes, resting pools are provided every five to ten metres for freshwater species. Slopes for Denil fishways usually range from 10% to 15% for adult freshwater fish (Katopodis 1990a). A slope of 15% equals 1.5 m vertical rise for 10.0 m horizontal run.

The relationship between Denil fishway depth, width, slope, water depth within the fishway, and lake and tailwater levels has been studied extensively at the University of Alberta Hydraulics Laboratory and a discharge rating curve developed (Katopodis and Rajaratnam 1983, 1984; Rajaratnam and Katopodis 1984; Rajaratnam *et al.* 1985).

$$Q_* = Q \,/\, (g\, S_0\, b^5)^{1/2}$$

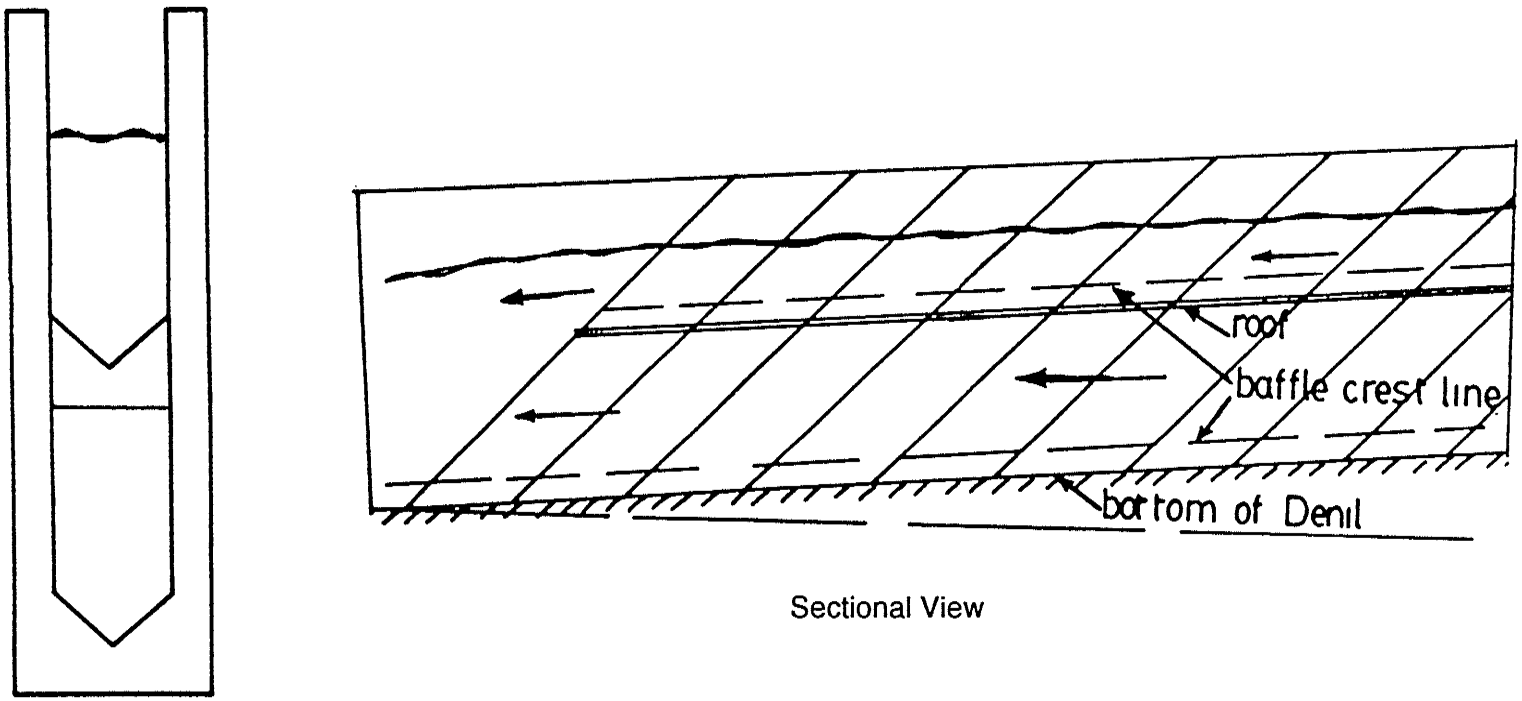
Where:
Q_* = dimensionless fishway discharge;
Q = fishway discharge (m^3/s);
g = acceleration due to gravity (9.81 m/s^2);
b = net passage width of the fishway (m);
S_0 = fishway slope (m/m);
d = water depth from baffle crest or "V" to water surface (m).

which equals: $$Q_* = 0.94(d / b)^2$$

Given the width (*b*) of the Cowan Dam Denil fishway and the slope of the upper flume the above equations reduce to $Q = 0.66d^2$. Using these hydraulic models it is possible to estimate the discharge through the fishway and to calculate predicted water velocities at different levels within the fishway.

Denil fishway - two-level

Water velocities in standard Denil fishways become excessive for fish passage when water depths within the fishway are too great. Standard Denil fishways built with a *d/b* ratio greater than 3 are known to have excessive velocities (Rajaratnam *et al.* 1987b), where *d* is the depth of water in the fishway measured from the water surface to the V-notch of the floor baffles, and *b* is the width of the open fishway channel between the side baffles (Figure 3). To remedy the problem of high velocities when d/b exceeds 3, the standard Denil design was modified by installing a roof at d equals 3b (Figure 4) (Rajaratnam *et al.* 1986). The results showed that the lower level Denil functioned as a standard Denil up to a flow depth of 3b, but when the flow exceeded this depth, the lower level Denil acted like a duct with a maximum velocity corresponding to 3b. The upper level carried the extra flow and performed as a standard Denil with a much reduced d/b ratio. With the two-level design the high velocities which existed in a single level Denil fishway were avoided, and the predicted fish passing capability of the fishway was improved.



Sectional View

Baffle Detail

Figure 4. Two-level Denil fishway (from Rajaratnam *et al.* 1986).

METHODS

DESCRIPTION OF THE STUDY AREA

The Cowan Dam Denil fishway is located at the north end of Cowan Lake, about 200 km northwest of Prince Albert, Saskatchewan (Figure 5). Cowan Lake, and its tributary streams, comprise the most southerly portion of the Churchill River drainage system. Cowan Lake has a gross drainage area of about 4,343 km^2 and an estimated effective drainage area of 1700 km^2 (Liaw 1978). Cowan Lake is long (50 km) and narrow (mean width 645 m), with a surface area of 32.3 km^2. At its licensed full supply level (FSL) of 476.13 metres above sea level (ASL), Cowan Lake has a maximum depth of 5.6 metres and a mean depth of only 2.5 metres. In 1976, over 75% of the lake surface area had dense growths of emergent and submergent aquatic plants due to Cowan Lake's shallow depth (Liaw 1978). It is also subject to dense annual summer algal blooms, and periodic winterkills of fish due to its shallow depth, nutrient rich drainage (from agricultural runoff and municipal sewage discharges), and thick deposits of wood debris on the lake bottom from past log rafting (Liaw 1978). Cowan Lake has relatively few fish species, compared to other lakes in the area (Table 1). Northern pike, white sucker, and yellow perch (*Perca flavescens*) are the only abundant large species. Walleye, cisco, lake whitefish and longnose suckers are scarce, probably due to low winter oxygen levels and a lack of suitable spawning habitat (Liaw 1978).

Cowan Dam was originally built about 1915 to raise and maintain water levels in Cowan Lake so that logs could be rafted to the sawmill in Big River. According to Liaw (1978), a fish ladder was part of the original dam. Records kept by gate keepers stationed at Cowan Dam documented that walleye,

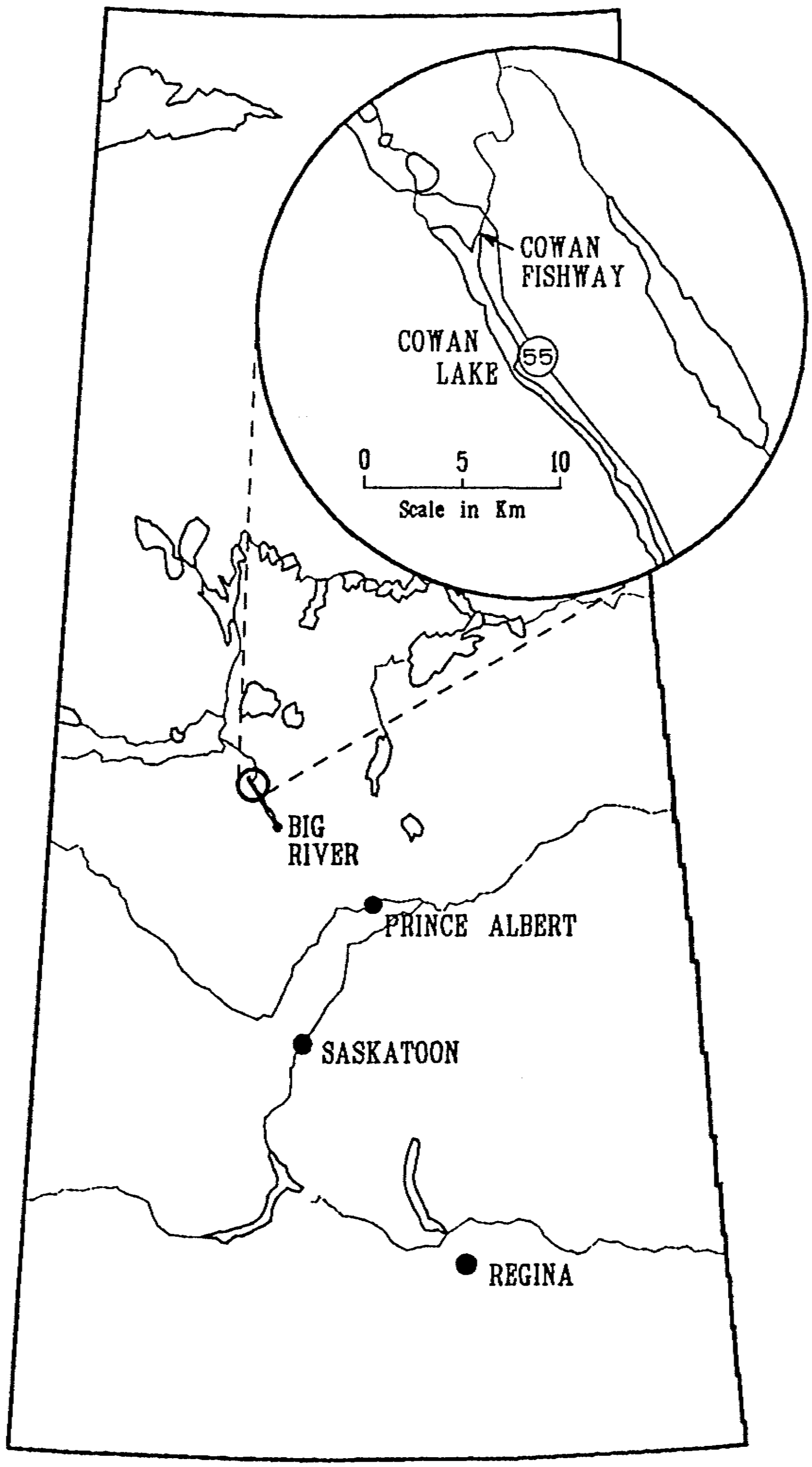


Figure 5. Map of Saskatchewan showing the location of the Cowan Dam fishway.

suckers, and pike moved through the fishway in 1928. No reference was made to the design of the fishway.

Table 1. Fish species abundance in area lakes.

Lake	Number of species	Reference	
Cowan	11	Liaw	1978
Delaronde	16	Liaw	1976
Dore	16	Sawchyn	1987
Ile-a-la-Crosse	18	Saylor	1972
Waterhen	14	Atton & Novakowski	1956

The present concrete dam was constructed by the Federal Department of Public Works in 1950 to replace the original timber crib dam which had been destroyed by fire the previous year. This dam consists of four, 4.9 m wide sluiceways, covering a length of 32 metres. Radial control gates in each sluiceway are operated to maintain lake levels at the licensed FSL of 476.13 ± 0.5 metres ASL.

A pool-orifice-weir fishway was installed beside the most northerly sluiceway when the dam was constructed. Although a gatekeeper's diary record (Liaw 1978) reports that large numbers of fish used the fishway in 1953, there are no records of fish passage between 1978 and 1984. A Denil fishway was installed during the winter of 1984-85 when major repairs were made to the dam, as the existing fishway was not effective. This standard design Denil fishway was built by the Saskatchewan Department of Parks and Renewable Resources (now Department of Environment and Resource Management) to restore fish access to spawning habitat above the dam, and to enhance fish populations within Cowan Lake. The fishway was first operated in the spring of 1985, and is located between the most southerly radial discharge gate and the south bank of the Cowan River.

SAMPLING PROCEDURES

Air and water temperatures

Air temperature and lake surface, fishway and tailwater temperatures were determined prior to each fishway cage lift using a hand held mercury thermometer. Daily pH measurements were taken in Cowan Lake and in the tailwater pool using a Hach pH kit.

Fish passage monitoring

Fishway cage - 1990: Fishway monitoring was carried out from April 26 to 28, and from May 1 to June 5, 1990. A blizzard forced monitoring to be abandoned on April 29 and 30. On June 5 the fishway was closed due to low water levels in Cowan Lake.

A 2.0 m x 2.0 m x 2.0 m fish counting cage, constructed of square tubular steel supporting 14 mm vertical x 35 mm horizontal expanded steel mesh walls and floor, was fixed to the upstream face of the dam at the fishway exit. Two steel mesh wings funneled ascending fish into the cage, and deterred them from returning down the fishway. The opening between the wings measured 2.0 metres high by 300 mm wide. The wings were hinged so that one could be closed over the fishway exit preventing fish loss from the cage during sampling.

A chain hoist attached to an overhead I-beam was used to raise the cage. Lifting the cage reduced the water depth within it and crowded the fish for easier sampling. Crowding also prevented the fish from segregating by size or sex when less than the total number of fish in the cage were weighed and measured.

The trap was usually lifted three times daily at about 900, 1500 and 1900 hours, to prevent fish from becoming overcrowded or stressed.

Downstream trap - 1990: On April 24 & 25, 1990, a trapnet was installed in the Cowan River approximately 300 metres downstream of Cowan Dam, in order to capture and tag upstream migrating fish. A 3.0 m X 3.0 m trap was installed on the south side of the river in 1.0 to 1.4 metres of water. Mesh wings (30 metres long X 1.8 metres deep X 25 mm square mesh) were angled off downstream to both banks of the river to block and lead upstream migrating fish into the trap. The leads were installed in a manner that prevented fish from passing upstream around or beneath them.

On the evening of April 25, 1990, Conservation Officers increased discharges through the dam control gates to reduce excessive water levels in Cowan Lake. The resulting high flows caused the downstream river level and current velocity to increase, breaking off a number of the lead posts and washing out the main trapnet lead on April 26. Repairs were made late in the afternoon of April 26. Due to continuing high flows, the lead was reinstalled only about one third of the way across the main river channel in order to prevent it from washing out again. Dam releases and river levels continued to increase, and by April 30, 1990 the trap and leads were completely submerged and no longer effective.

Cowan River water levels dropped sufficiently by May 8, that downstream trap netting could resume. The trap was operated with limited success between May 8 and 20, and then with almost no success until May 29 when the trap was removed. With the failure of the trap to provide sufficient fish for tagging, a 15 m X 1.8 m by 6.5 mm^2 mesh seine net was used in the tailwater pool immediately below the dam. Although the seine was not very efficient in the turbulent conditions of the tailwater pool, it provided the only practical means to collect additional fish for tagging.

Fishway cage - 1991: In 1991, fishway monitoring was carried out between April 23 and 27, and on May 4, 8, 12, 17, and 23. On April 23, 1991, the fish counting cage was divided into two fish holding sections in order to separate fish which ascended the different levels of the two-level fishway. Although the divider panels effectively separated the fish, they did not retain them efficiently as many were observed leaving the cage and returning down the fishway.

Because the divided cage proved to be ineffective at retaining fish, an attempt was made to visually observe fish leaving the fishway exit after ascending the fishway. A monitoring system was developed whereby visual counts of fish leaving the fishway exit were carried out for 30 minutes of every 90 minutes. The 30 minute observation periods commenced at 830, 1000, 1130, 1300, 1430, 1600, 1730, and 1900 hours on each day of visual monitoring. Visual observation of fish movements took place on April 25, and May 3, 7, 11, 16, and 22, 1991. The fishway cage was operated on each following day to obtain total counts of ascending fish, and to capture fish for sampling.

Visual observation proved to be effective for monitoring fish which ascended the upper fishway level, but was unreliable for observing the lower level due to reduced visibility at depth.

Video monitoring - 1992: In 1992, a video camera encased in an underwater housing was used to monitor fish movements through both the upper and lower levels of the fishway. Video monitoring was carried out for 15 minutes every hour from 1200 to 1900 hours on April 21 and 26, and from 1100 to 1900 hours on May 3 and May 10, 1992. Monitoring spanned the period of peak spring migration. Low water levels in Cowan Lake forced the closure of the radial control gates on the evening of May 10.

All counting periods commenced when the video camera was turned on and continued for precisely 15 minutes. Fish which were videotaped but did not ascend during the 15 minute monitoring period were not included in the analysis.

Fish measurements

During both the 1990 and 1991 field seasons, standard fish measurements were obtained from samples of fish at each of the fishway cage lifts. Random samples of each species were weighed to the nearest 25 grams using a spring scale; fork length was measured to the nearest millimetre; and sex and spawning condition data were recorded. When it was not possible to positively identify the sex or sexual maturity of a fish during the spawning migration, it was sacrificed and its gonads examined. A positive identification was made in all cases. Spawning male white and longnose suckers were easily differentiated from females by the presence of well developed nuptial tubercles on the rays of the anal fin (Scott and Crossman 1973). Spawning condition for all species was noted as green, expressing, ripe, and spent. Green fish were defined as those that would not express eggs or milt unless firm pressure was applied to the fish's abdomen. Expressing fish would release a few eggs or milt when moderate pressure was applied. Ripe fish expressed eggs or milt with normal handling. Spent female fish were flaccid and released watery fluid and a few eggs when squeezed, while spent males expressed only a trace of milt when squeezed.

Aging structures were collected from samples of all fish species which utilized the fishway. In 1990, otolith and scale samples were collected from walleye, whitefish and cisco, and cleithra and scale samples were obtained from northern pike. In 1991, additional scale and otolith samples were collected from walleye, additional cleithra were collected from northern pike, and pectoral fin rays were collected from white and longnose suckers. The aging structures collected for each species were selected in accordance with recommendations by Musker (1985).

Scale samples for all species were taken from a position above the lateral line on the left-hand side of the fish. Finrays were obtained from the left pectoral fin of white and longnose suckers for aging. The marginal and second rays were clipped as close to the body as possible. All aging samples, with the exception of pike cleithra, were prepared for aging by the Saskatchewan Fisheries Laboratory in Saskatoon according to methods described by Musker (1985). Cleithra required no special preparation for aging other than cleaning.

All samples were aged by the author and each aging structure was read twice, separated by a period of two to three weeks. After the final reading, the ages were compared. If there was any difference between the two readings, the structure was re-aged with the third reading taken as being correct. Since determination of the position and shape of the first annulus is critical in assigning reliable ages to white sucker finrays (Beamish 1973), photographs in Chalanchuk (1984) were used as a guide.

Fish tagging

Fish were tagged at two locations below the fishway in 1990. Most early season tagging occurred at the fish trap installed about 300 metres down river of the dam. Because high discharges through the dam soon made trapping at this site impossible, fish were obtained for tagging by seining and angling in the tailwater pool immediately below the dam. Additional fish were tagged in 1990 and 1991 at the fishway cage after ascending the fishway. No fish were tagged downstream of Cowan Dam in 1991.

All fish were tagged using #1005 Size 4 monel chicken wing tags. Tags were installed on the left operculum of all species at the 2:00 o'clock position. All tags applied were examined to ensure they were properly clinched and would not be lost or injure the fish's gills. All fish captured in the fishway cage were examined for tags or for signs that a tag had been lost.

Fish were not anaesthetized during tagging as released fish might have been caught and consumed by anglers prior to expiration of Agriculture Canada's mandatory six week drug withdrawal period. In two separate trials, samples of tagged fish were held in a holding pen for 48 hours to check for tagging mortality.

DESCRIPTION OF THE FISHWAY

Standard Denil fishway

The Denil fishway at Cowan Dam consists of three rectangular flumes equipped with planar baffles on the sides and bottom, two resting pools and two vertical lift control gates. Figure 6 shows the plan view of the fishway; Figure 7 shows the elevation views. The Cowan Dam fishway has the following physical dimensions: fishway slopes are 12.6% for the upper flume, and 10.0% for the middle and lower flumes. The flume lengths are 9.5 m (upper), 6.0 m (middle), and 8.5 m (lower). The net passage width of the flumes is 400 mm. The upper resting pool measures 2.35 m long X 1.45 m wide, while the lower resting pool is

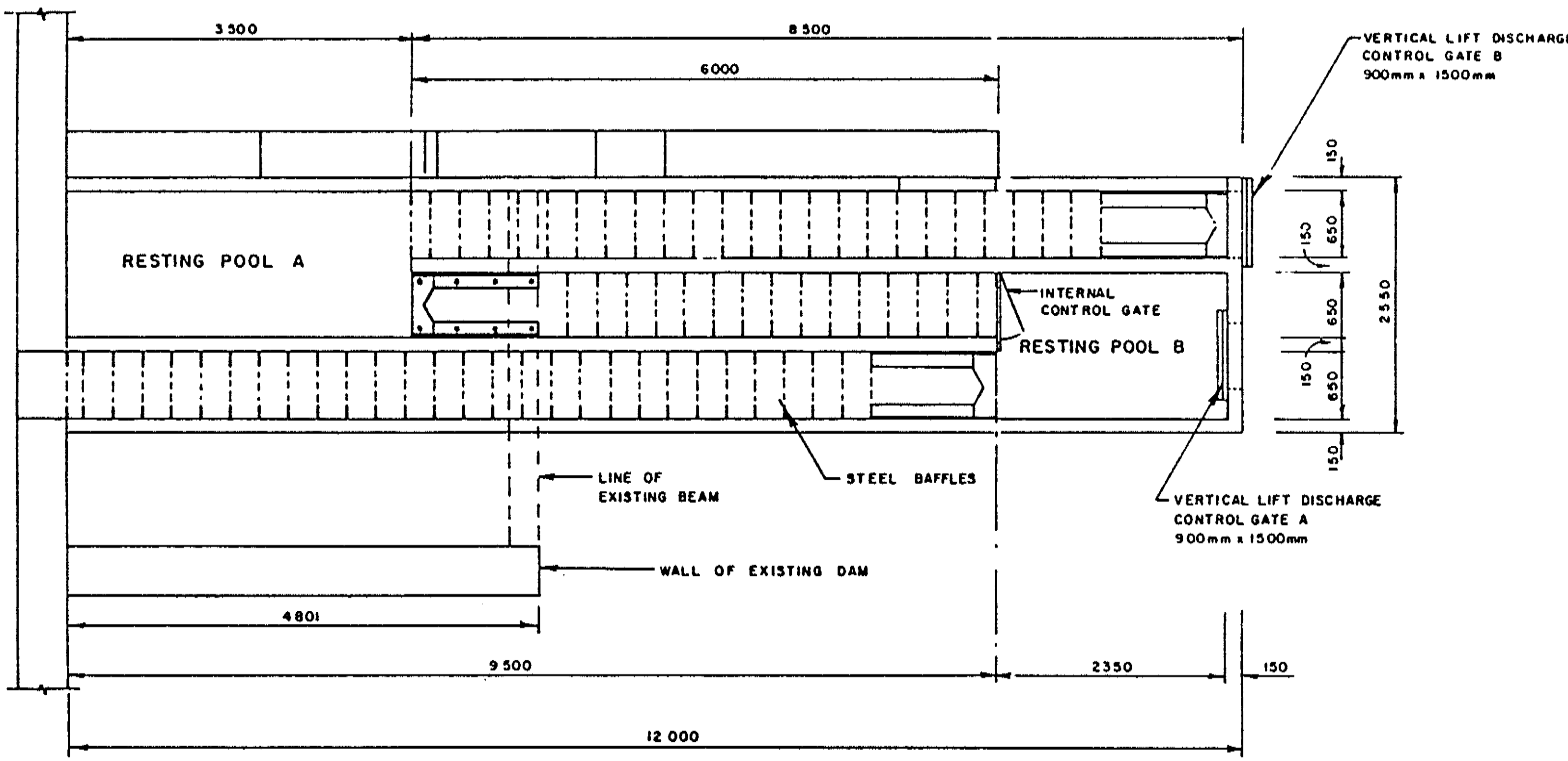


Figure 6. Plan view of the Cowan Dam Denil fishway (all measurements in mm).

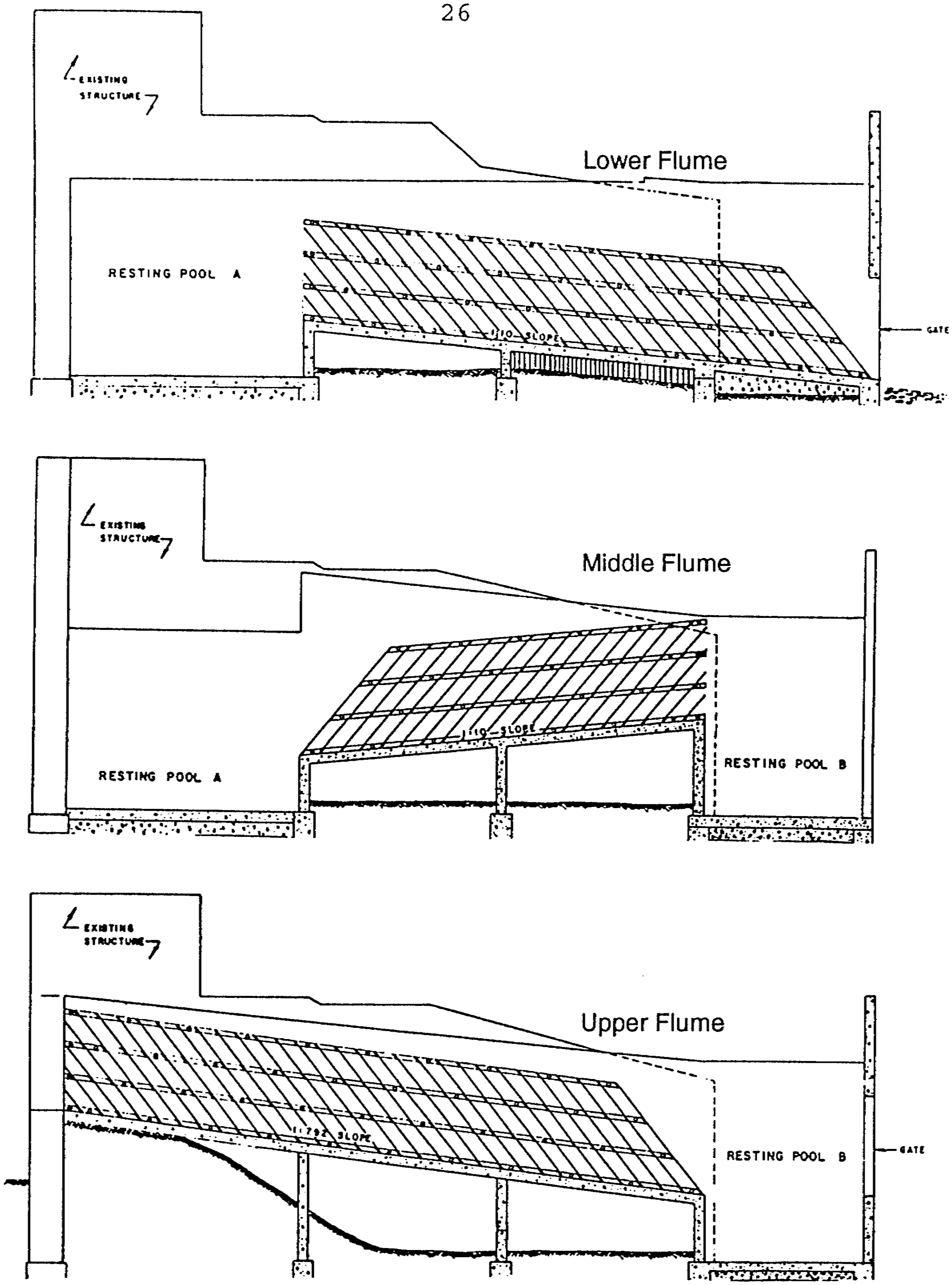


Figure 7. Elevation view of Cowan Dam Denil fishway.

3.50 m long X 1.45 m wide, and both are 2.5 m deep. The difference in fishway floor elevation between the water inlet (fish exit) and water outlet (fish entrance) is 2.2 metres. The control gates at the outlet of the upper and lower flumes allow for the operation of all three flumes when the tailwater level is low, or only the upper flume when the tailwater is high.

In 1985, due to high flows through the dam, and therefore high tailwater levels, only the upper flume was operated (Katopodis *et al.* 1991). Although the control gate on the lower flume was also left open, very little of the fishway flow exited via this route. In all three years of this study (1990, 1991, and 1992), low discharges through the dam, and therefore low tailwater levels, required that fish ascend all three flumes in order to pass over the dam.

As was done in 1985, the dam discharge (excluding flows through the fishway) was released through the two radial control gates closest to the fishway. The release was done in such a manner that fish following along the outside edge of the zone of greatest turbulence, marked by the edge of white water, would be led to the outlet flow from the fishway entrance. Attracting fish to the fishway entrance is the single most important factor in the success of a fishway (Katopodis and Rajaratnam 1983).

Two-level Denil fishway

The standard Denil fishway at Cowan Dam was modified in 1991 to determine whether reduced water velocities in a two-level fishway would improve fish passage performance. Since water depth in the upper fishway chute exceeded d/b = 3.0 only 1% of the time in 1990, a d/b depth of 2.0 was chosen for the location of the lower level fishway roof. Figure 8 shows calibration curves for two-level Denil fishways. This chart shows that a second fishway level

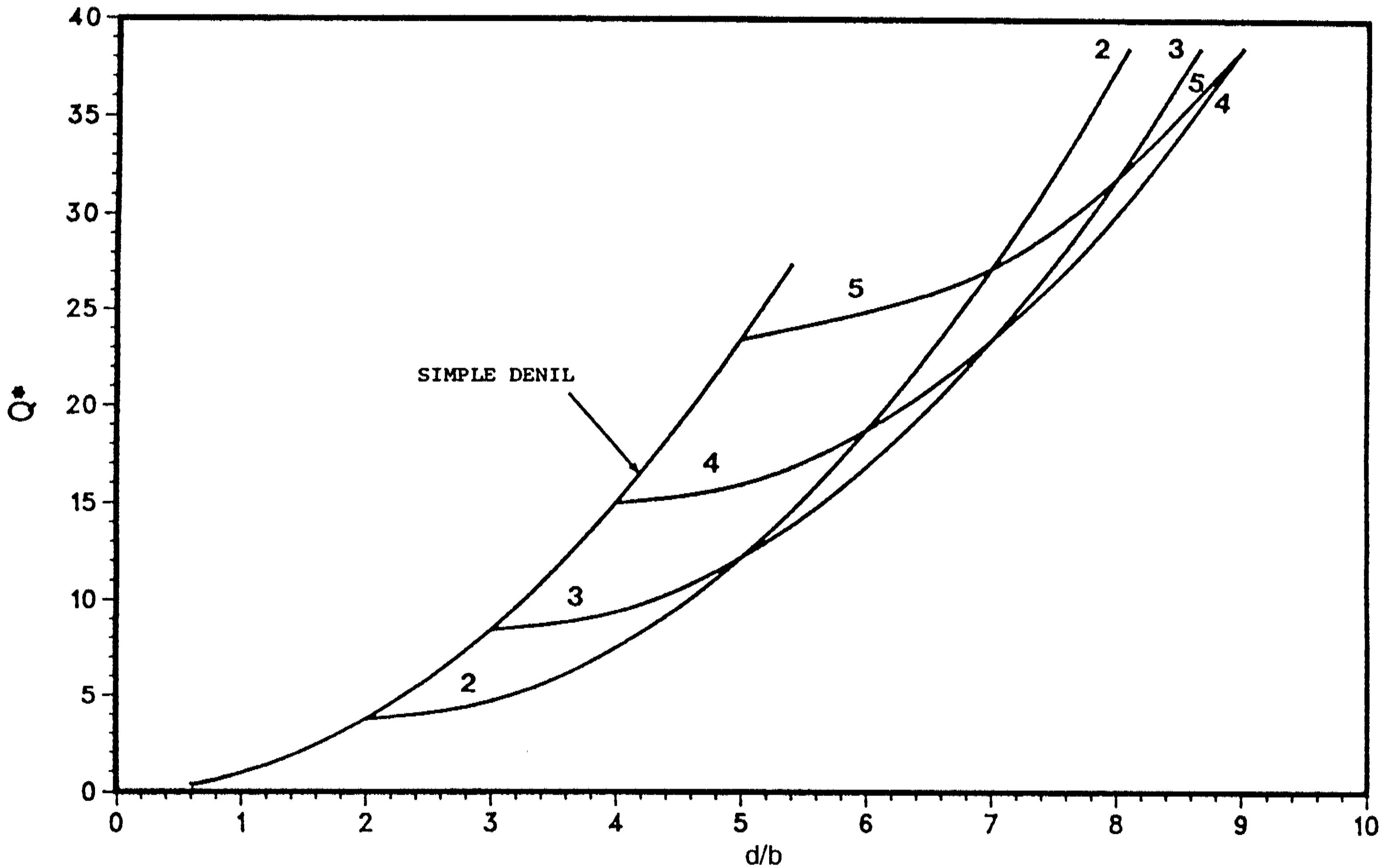


Figure 8. Calibration curves for two-level Denil fishways (from Rajaratnam *et al.* 1986).
Where Q* = dimensionless fishway discharge
d = water depth in fishway
b = net passage width of fishway

installed at d/b = 2.0 would result in a greater reduction in water flows, and therefore velocities, than would a d/b ratio of 3.0.

In order to monitor a two-level Denil fishway it is necessary that flow depths greater than the roof of the lower fishway be maintained at all times. It would be impossible to measure water depths in the lower level fishway under less than full conditions, due to the presence of the upper level fishway floor. The floor and baffles of the upper level fishway were constructed of 19 mm (3/4") thick fir plywood. The dimensions of the floor baffles of the lower fishway level were replicated for the upper level. Only the upper chute of the fishway was equipped with two-levels, since there was no practical way to keep fish separated in the fishway resting pools.

Hydraulic monitoring

In 1990 and 1991, water level measurements were recorded at 16-18 locations and 21 locations within the fishway respectively, at about 900, 1500 and 1900 hours. Cowan Lake water level and the tailwater level were recorded as well. The number of handwheel revolutions which the dam's radial control gates were open was also recorded in order to calculate overall dam discharge rates.

DATA ANALYSIS

Diurnal movement of fish species through the fishway in 1990 was analyzed using a "G" test for goodness of fit (Sokal and Rohlf 1981). The test compares the observed number of fish which ascended the fishway with the expected number if ascending fish were proportioned equally over the three fishway cage lift periods. The expected numbers for each species were calculated by multiplying the total number of fish which ascended the fishway by the percent of total time that the counting cage was in place during a given lift period. Unless otherwise indicated, all G tests were carried out using William's correction to better approximate a chi-square distribution as recommended by Sokal and Rohlf (1981).

Although the standard G test will determine whether there is a significant difference between the actual and expected numbers of fish which ascended the fishway during the three lift periods, it does not indicate where the differences are found. While it is not generally recommended to carry out all possible pair-wise comparisons using G tests because of the increased possibility of finding significant differences which are due to chance alone, no other valid test could be found.

To minimize the possibility of rejecting the null hypothesis when there was no difference, the pair-wise G tests were applied so that they would be very conservative in finding a result significant. A continuity correction was applied to the pair-wise tests, although Sokal and Rohlf (1981) suggests that this correction is overly conservative. As well, the level at which a result would be deemed significant was arbitrarily reduced to ($P < 0.01$).

G tests were also used to compare: the numbers of white suckers, longnose suckers, walleye and northern pike which ascended the fishway in 1985 and 1990; movement through the fishway of white suckers tagged at the downstream trap and in the tailwater pool; and, the average delay periods before white suckers tagged at the downstream trap and tailwater pool ascended the fishway.

Where G tests would have been suitable but sample numbers were too low ($n<25$), actual calculated binomial probabilities were used (Sokal and Rohlf

1981). They were used to compare the rate of tagged northern pike recaptures from different tagging locations; and, the proportion of fish movements through the upper and lower levels of the two-level fishway.

Comparisons of mean fork lengths for species sampled at more than one location were done using unpaired t-tests. Comparison of the sex ratios of species sampled at the fishway cage and below the dam, and comparison of the rate of tagged walleye recaptures from different tagging locations was done using a test for the difference in population proportions (Khazanie 1986).

Fishway water level measurement data was sent to the Freshwater Institute in Winnipeg for calculation of estimated water flows and velocities within the fishway. The equations used can be found in Katopodis (1990a). Station C was selected to estimate fishway discharge and velocity because it was relatively free of backwater effects, and is located in the uppermost fishway chute. Fish passage is most limited in this chute due to high water velocities, and its being four metres longer than the middle chute.

Unweighted least squares linear regressions were used to analyze the relationships between: fish length and weight; fish movement through the fishway and water velocity at various depths within the fishway; fish movement and fishway attraction flows; and, fish movement and the effect of changes in total hydraulic head between the lake surface and tailwater level.

For analysis of fish movements against hydraulic parameters such as fishway velocity, hydraulic head and attraction flows, only the periods of peak fish movement for each species were compared (Table 2). Because only 10 whitefish ascended the fishway in 1990, no attempt was made to analyze their movement in relation to hydraulic conditions.

Table 2 . Peak movement periods for each species in 1990.

Species	Peak movement period (inclusive)		
Walleye	May 4	to	May 8
Northern pike	May 21	to	June 5
White sucker	May 3	to	June 5
Longnose sucker	May 4	to	May 15
Cisco	May 28	to	June 5

Weighted least squares linear regressions (Steel and Torrie 1980) were used to analyze daily changes in the mean length of northern pike and white suckers. They were also used to compare daily changes in mean length with fluctuations in fishway water velocity over the peak movement period. Before carrying out either weighted or unweighted linear regression analysis, all variables were checked for normality using Wilk-Shapiro rankit plots. Any distributions found to be non-normal were normalized using a log transformation prior to analysis.

All regressions were tested for significance by determining whether or not the regression slope was equal to zero. The hypothesis used was Ho: $\hat{B}=0$ versus Ha: $\hat{B}\neq 0$.

The estimated numbers of northern pike and white suckers present in the tailwater pool below Cowan Dam were calculated using Petersen's mark-recapture formula modified to give an unbiased or "best" estimate of true population size (Ricker 1975);

$\hat{N}=\dfrac{(M+1)(C+1)}{(R+1)}$ where:

$\hat{N}$ = the estimated population size
M = the number of fish marked
C = the number of fish captured
R = the number of recaptured fish in the sample

Ninety-five percent confidence intervals for the population estimate were calculated by adjusting the recapture of marked fish from a Poisson distribution to a normal one using the following formula, (Lackey 1974):

95% confidence interval for $\hat{N} = R + 1.92 \pm 1.96\sqrt{R+1}$

The resulting values for recaptured fish were then substituted into the population estimation formula to obtain 95% confidence intervals for population size. Population estimates were made for the tailwater pool only, since the severe cold weather, which occurred after tagging and releasing most of the fish caught at the downstream trap, caused most fish to return back downriver.

RESULTS

STANDARD DENIL FISHWAY - 1990

Air and water temperature

Mean daytime air and fishway water temperatures were obtained by averaging all temperature measurements recorded each day. Mean water temperatures declined sharply in late April because of a period of unusually cold weather and a late spring blizzard. Due to the severity of the blizzard, no monitoring was carried out on April 29 or 30. Between May 1 and May 6, water temperatures increased steadily due to a period of warm weather. Following a brief cold period that caused water temperatures to decline by about 2°C, water temperatures increased to almost 20°C by May 28. More cool weather caused water temperatures to decline during the last week of monitoring (Figure 9). Water temperatures in the fishway were the same or within 0.5°C of lake surface and tailwater temperatures throughout the 1990 monitoring period.

Daily pH measurements in Cowan Lake and in the tailwater pool stayed between 8.4 and 8.6 for the duration of the 1990 study.

Fish species

General: A total of six fish species ascended the Cowan Dam Denil fishway in 1990. In addition to northern pike, walleye, white sucker and longnose sucker which were documented in 1985 (Katopodis *et al.* 1991), cisco and lake whitefish used the fishway in 1990. In total, 5685 fish comprised of 4031 white suckers, 1088 longnose suckers, 260 walleye, 181 northern pike, 113 cisco and 12 whitefish were counted in the fishway trap after ascending the fishway in 1990. All fish movement through the fishway stopped during, and for a few days

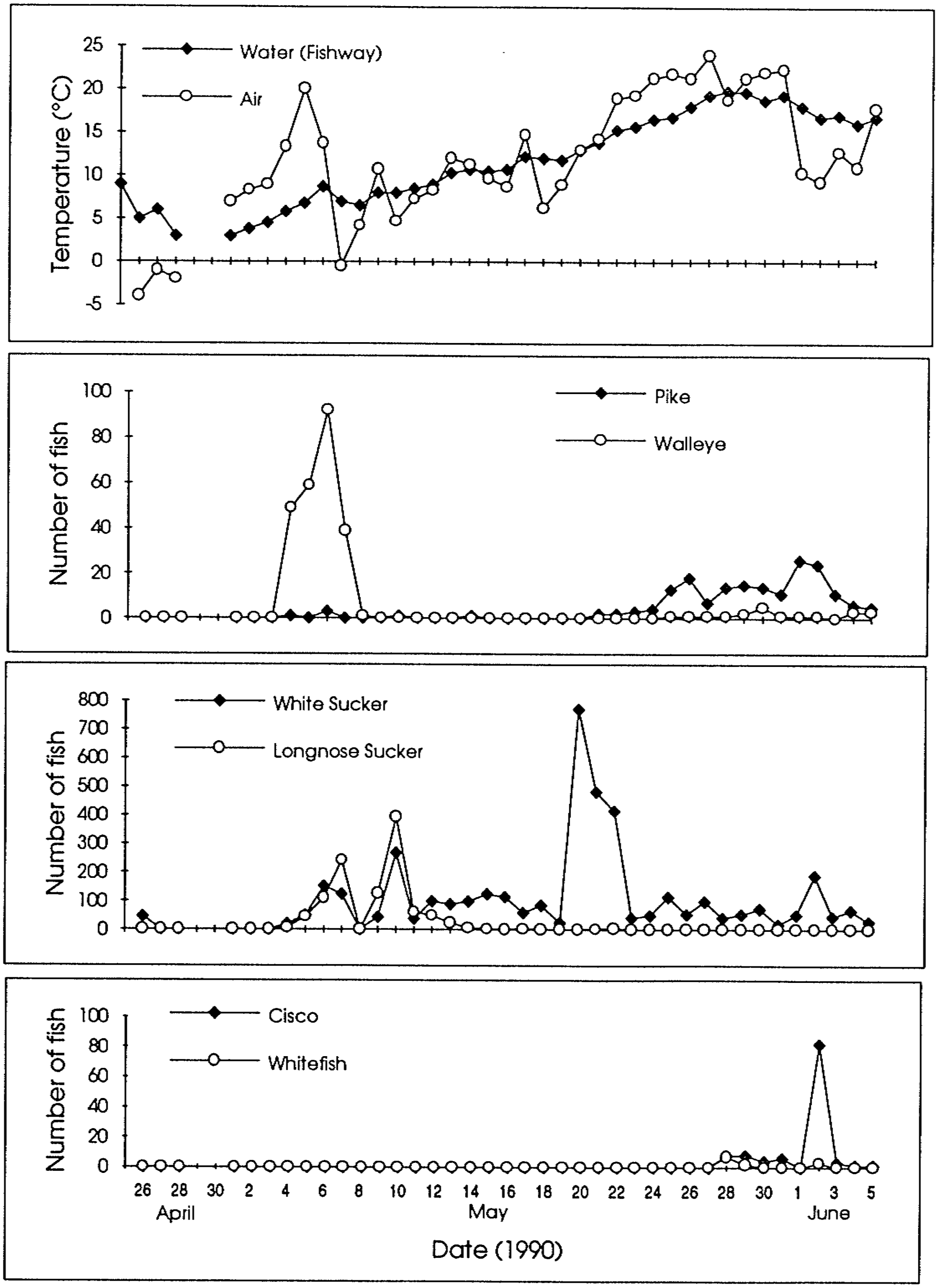


Figure 9. Temporal changes in water temperature and numbers of fish ascending the fishway.

following, the late April blizzard, and again during the May 7 and 8, 1990 cold spell. In spite of the 1985 monitoring period (17.5± days) being less than half as long as the 1990 period (41 days), significantly greater numbers of all species (excluding cisco and whitefish), utilized the fishway in 1985 (Table 3).

Tagging did not result in any obvious fish mortality. In two separate trials, a total of 26 fish, comprised of 20 white suckers, 4 northern pike, and 2 walleye, were held in a holding pen to check for tagging mortality. None of the test fish died or appeared moribund after being held for 48 hours. No fish observed at the fishway exit cage in 1990 showed any sign of tag loss.

Northern pike: The majority (96.7 %) of northern pike ascended the fishway during a 16 day period in late May and early June. Movement commenced when the mean fishway water temperature reached 13.8°C, and peaked at 17.0°C (Figure 9). Pike captured at the downstream trapnet on April 26 and 27, 1990 consisted of 67% pre-spawning fish and 33% spent fish, indicating that most pike reached the area below Cowan Dam prior to spawning. Pike were observed spawning in shallow water over flooded grasses in the area of the downstream trap. Throughout the period of the study, almost all of the pike that ascended the fishway did so after spawning had occurred. In 1990, only 3 pike ascended the fishway prior to spawning. All pike ascending after May 6 (98.3 %) were spent, with the exception of a single immature pike that ascended on May 30. Northern pike movement through the fishway was greatest during the period between 0930 hours and 1900 hours (daily cage lifts 2 and 3). There was no significant difference between rates of passage during this period. The lowest rate of passage occurred at night between 1930 hours and 0900 hours the following day (cage lift 1) (Figure 10).

Table 3. Numbers of fish which ascended the Cowan Dam Denil fishway during the 1985 (17.5 days) and 1990 (41 days) monitoring periods.

Species	Year			
	1985[a]		1990	
	Number	Frequency (%)	Number	Frequency (%)
Northern pike	1095[b]	9.7	181[b]	3.2
Walleye	342[c]	3.0	260[c]	4.6
White sucker	5054[d]	44.7	4031[d]	70.9
Longnose sucker	4803[e]	42.5	1088[e]	19.1
Cisco	0	0	113	2.0
Lake whitefish	0	0	12	0.2
Totals	11,294		5685	

a - 1985 data from Katopodis *et al.*, 1991.

b to e - The number of fish which ascended the fishway in 1985 was significantly different from the number which ascended in 1990 for northern pike, walleye, and white and longnose suckers (G test; $P < 0.005$). Cisco and lake whitefish numbers were not compared between years due to low numbers ascending the fishway in 1990, and less complete sampling in 1985.

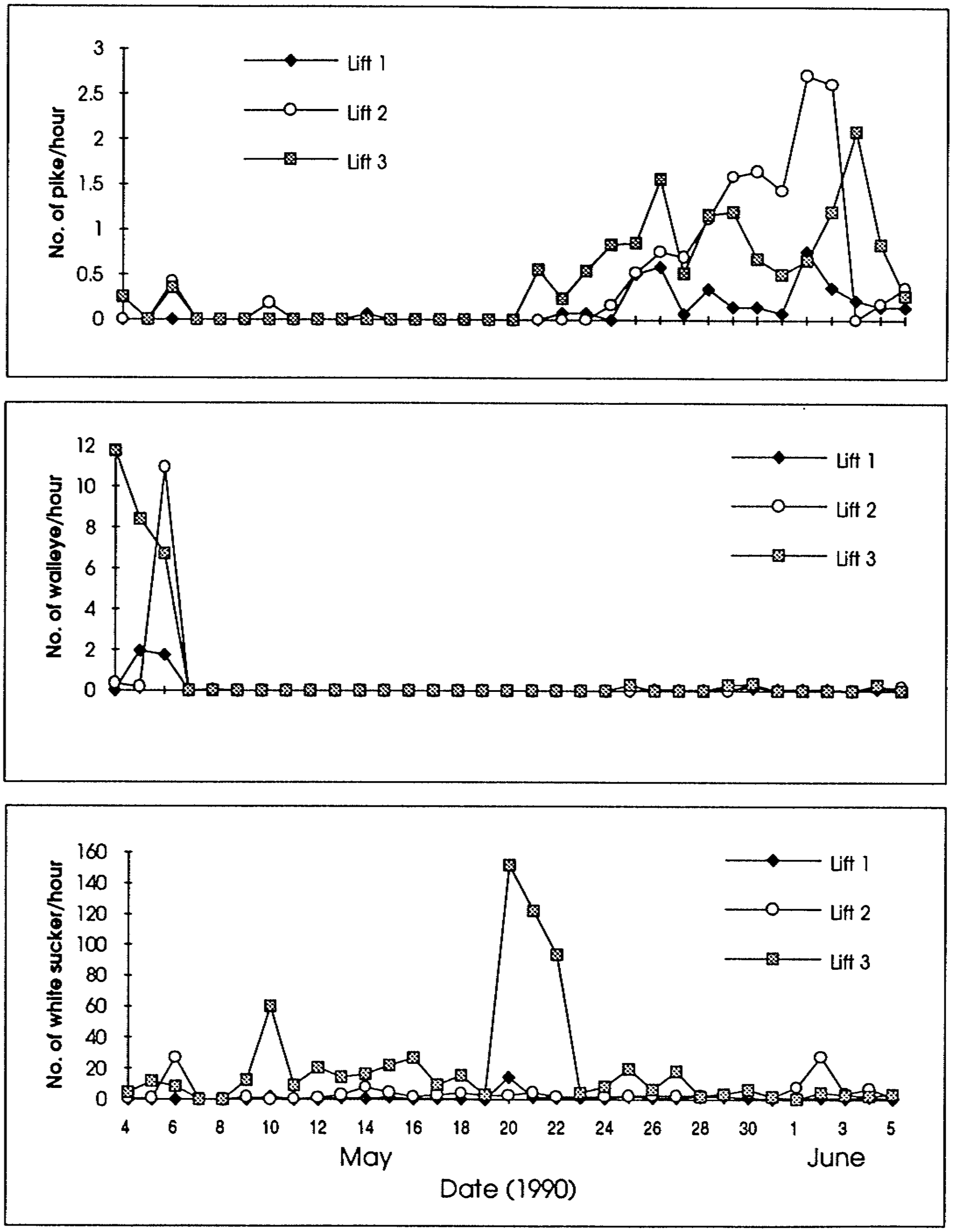


Figure 10. Diurnal movement of northern pike, walleyes and white suckers.

The length - weight relationship of 177 northern pike captured at the fishway cage in 1990 was $W = 0.0134\ L^{2.8273}$. The pike length distribution is strongly skewed towards the smaller pike. Almost 82% of fish measured between 40 and 60 cm in length, while less than 6% were between 60 and 80 cm long (Figure 11). Very few pike less than 40 cm length ascended the fishway. Northern pike sampled at the fishway cage were significantly shorter than pike sampled at the downstream trap and in the tailwater pool. There was no difference between mean lengths of pike sampled at both tagging locations below the dam however (Table 4).

Table 4. Mean fork lengths (cm) of northern pike sampled at Cowan Dam in 1990.

Location	Mean length	Standard deviation	Number of fish
Fishway cage	47.0*	8.75	181
Downstream trap	52.3	11.21	63
Tailwater pool	52.6	7.78	32
Below dam Combined	52.4*	10.14	95

* - Significantly different at $P < 0.01$

The mean length of northern pike captured in the fishway exit cage declined over the course of the 1990 monitoring period (Figure 12). Both sexes were combined for analysis due to the relatively small numbers of pike that ascended the fishway.

Mean pike age obtained using scales was 4.8 years (n = 22); mean age

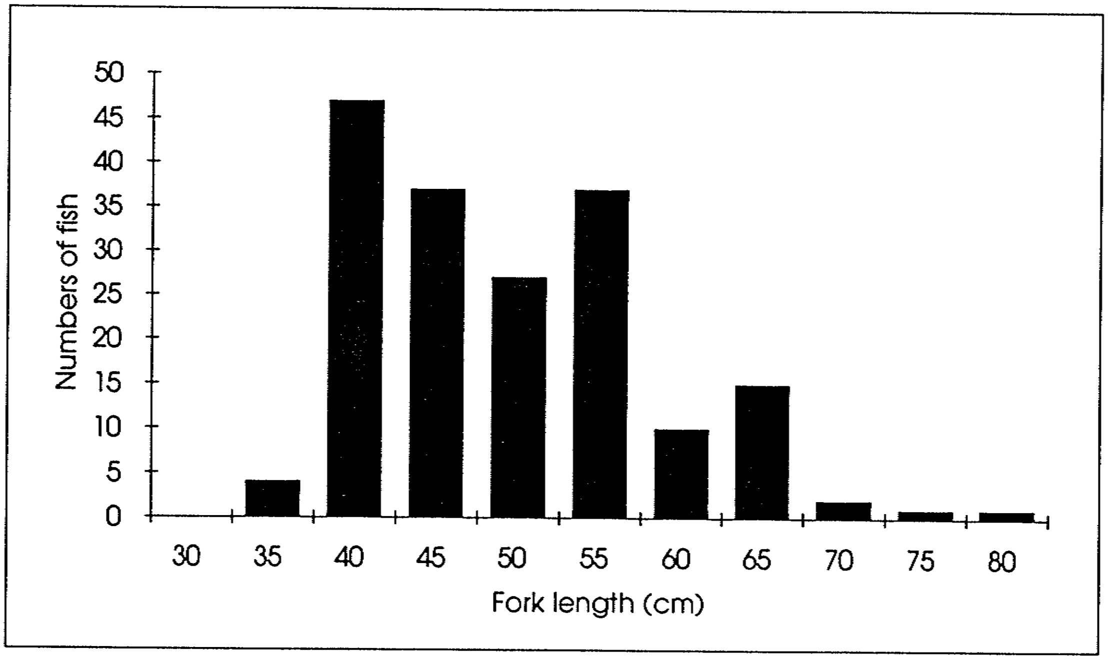


Figure 11. Length distribution of northern pike at the fishway cage in 1990.

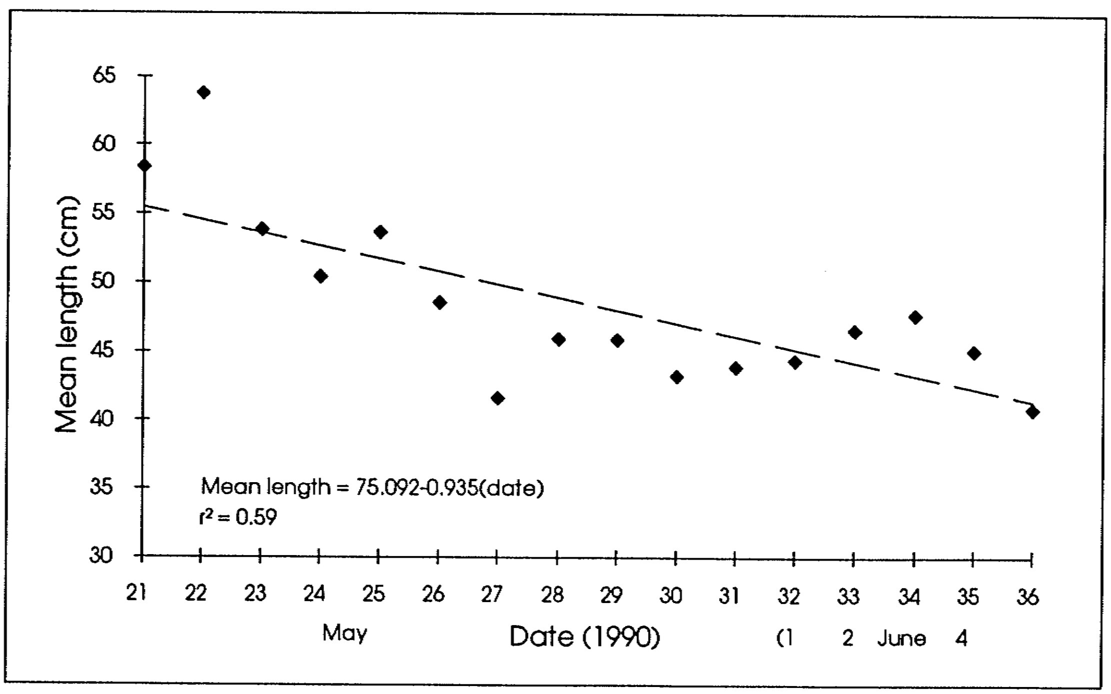


Figure 12. Temporal changes in mean lengths of northern pike during the 1990 monitoring period.

obtained from cleithra was 6.2 years (n = 31). Northern pike ages obtained from cleithra and scales corresponded well to about seven years of age, but fish aged at 10 to 12 years using cleithra, consistently aged three to four years younger according to scales. Pike which ascended the fishway ranged in age from three to twelve years according to cleithra (Figure 13). Both sexes entered the spawning migration at three years of age. The proportion of male (20) to female (14) northern pike that ascended the fishway was not significantly different from the proportion of males (23) to females (24) sampled at the downstream trap ($P < 0.05$).

Sixteen (84.2%) of the 19 northern pike lethally sampled at the fishway cage were found to have empty stomachs. The stomachs of the remaining three fish contained amphipods only.

Of 226 northern pike tagged in 1990 and 1991, a total of 18 were recaptured and reported by anglers (Appendix 2). This represents a minimum overall harvest rate of tagged fish of about 8.0% (Table 5). The recapture rate of pike tagged at the fishway cage after ascending the fishway was significantly lower than for pike tagged below the dam.

Of 154 pike tagged at the fishway cage, three were recaptured in Cowan Lake and one was caught in the tailwater pool below the dam. Of 72 pike tagged below the dam, anglers recaptured eight within 300 metres of the tagging location, one just above the dam in Cowan Lake and four after they returned downriver. The fourteen pike recaptured in the Cowan River below the dam or in Cowan Lake were caught an average of 14.3 days after tagging, a mean distance of 0.9 km from Cowan Dam. Four pike that returned downriver prior to being caught were at large an average of 273 days after being tagged. They were recaptured an average of 118 km from Cowan Dam. The pike caught the

Table 5. Recapture of tagged northern pike by anglers.

Tagging location	Year	Number tagged	Number recaptured	Recapture rate (percent)
Fishway cage	1990	98	3	3.1[a]
Below dam	1990	72	14	19.4[a,b]
Fishway cage	1991	56	1	1.8[b]
Total		226	18	8.0

[a] & [b] - Significantly different from expected rate of recapture if tagged fish were caught with equal likelihood from each tagging location ($P < 0.0005$).

furthest distance from Cowan Dam was caught in the MacBeth Channel between Lac Ile-a-la-Crosse and Churchill Lake, a distance of about 230 km. The fish was at large 272 days. Figure 15 shows the distribution of tagged pike recapture locations.

Only four of 72 pike tagged at the downstream trap and in the tailwater pool in 1990, were recaptured after ascending the fishway. Northern pike tagged in the tailwater pool appeared to ascend the fishway sooner after tagging than did pike tagged at the downstream trap (Figure 14), however the difference was not significant ($P>0.05$). The observed delay period between date of tagging and date of fishway ascent was 27 days (n=1) from the downstream trap, and an average of 11 days (n=3) at the tailwater pool.

Petersen mark-recapture estimates of population abundance were calculated using northern pike tagged in the tailwater pool only, because of the differences in delay periods between the downstream trap and tailwater pool. A

Figure 13. Age composition of northern pike sampled at the fishway cage in 1990.

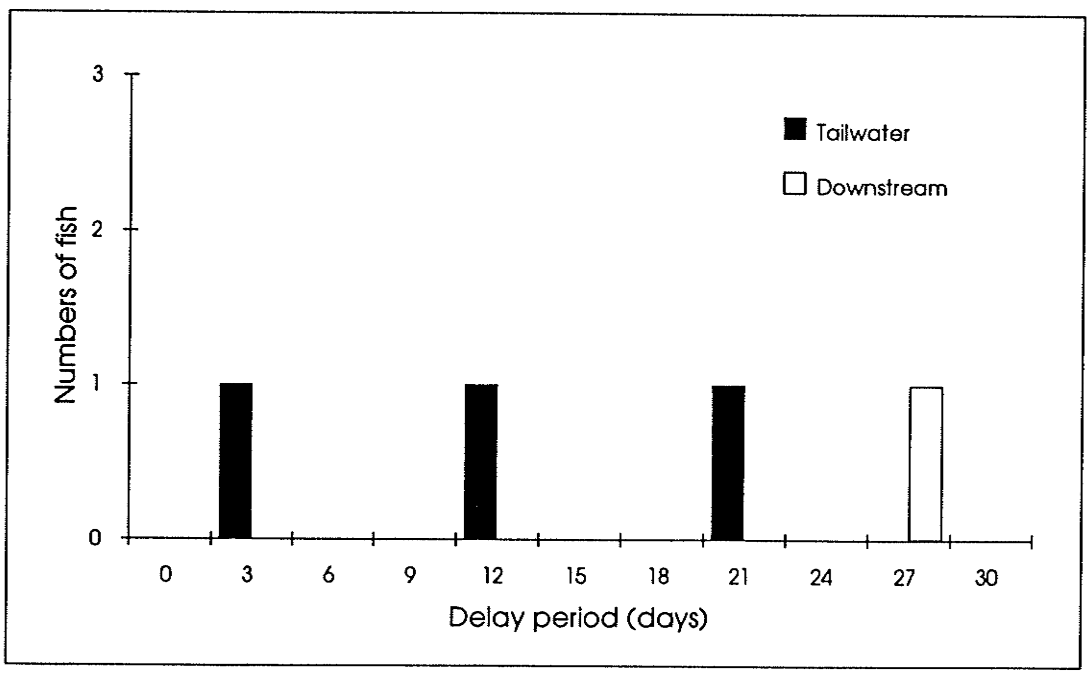


Figure 14. Delay period between tagging northern pike at the downstream trap and in the tailwater pool in 1990, and their recapture after ascending the fishway.

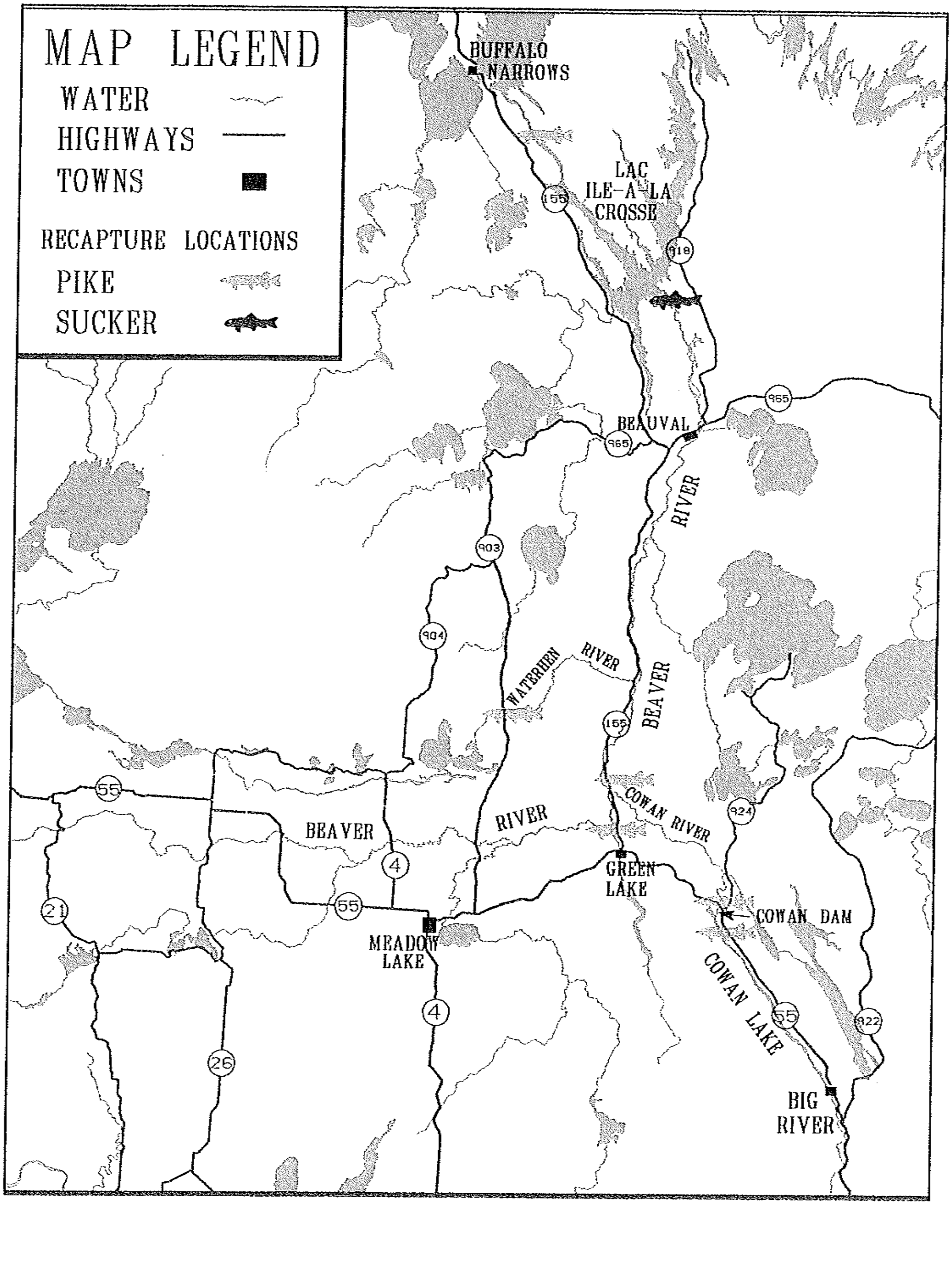


Figure 15. Distribution of tagged pike and sucker recapture locations.

total of 181 northern pike were examined for tags at the fishway exit cage in 1990, however, only three of 32 pike tagged in the tailwater pool were recaptured. Based on this rate of recapture, it is estimated that the population of northern pike in the tailwater pool numbered about 1500 individuals. Lower and upper 95% confidence intervals of the estimated population size are 610 and 3003 individuals respectively. The effectiveness of the fishway for pike passage was also calculated. With a population size estimated to be 1502 fish, the 181 pike that ascended the fishway represent a passage rate of 12.1 percent. Lower and upper 95% confidence intervals for estimated passage rate are 6.0% and 29.7% respectively.

<u>Walleye</u>: Peak walleye movement occurred over a four day period in early May (Figure 9). Walleye movement commenced when the daily average fishway water temperature reached 5.8°C, and peaked when it reached 8.7°C. Of 260 walleye captured in the fishway cage, 239 (91.9%) ascended the fishway during this period.

All of the walleye that ascended the fishway in early May were in pre-spawning condition. This represents 92.3% of the total walleye that utilized the fishway in 1990. The remaining walleye ascended the fishway sporadically in late May and consisted of 75% spent and 25% immature fish. The greatest rate of walleye passage through the fishway took place between 1530 hours and 1900 hours (daily cage lift 3); see Figure 10. The next greatest rate of passage occurred between 0930 hours and 1500 hours (cage lift 2). The time of day with the lowest rate of passage was the period between 1930 hours and 0900 hours the following day (cage lift 1).

Six (85.7%) of the seven walleye lethally sampled at the fishway exit cage were found to have empty stomachs. One walleye had eaten two small yellow perch.

A comparison of walleye sampled from the fishway cage and downstream trap found the populations to be similar. The length - weight relationship of 186 walleye captured at the fishway cage in 1990 was $W = 0.0043\ L^{3.2635}$. The length distribution of walleye captured in the fishway cage is shown in Figure 16. The mean lengths of walleye sampled at the fishway cage and at the downstream trap were not significantly different (Table 6). The mean length of mature male walleye was 42.4 cm. This is significantly shorter than the mean length (47.1 cm) of sexually mature females (t-test, $P < 0.001$). The male to female ratio of known sex walleye that ascended the fishway was 9.4 to 1.0. This was not significantly different ($P < 0.05$) from the sex ratio of walleye sampled at the downstream trap.

Table 6. Mean fork lengths (cm) of walleye sampled at the fishway cage and at the downstream trap in 1990.

Location	Mean length	Standard deviation	Number of fish
Fishway cage	42.4*	4.01	260
Downstream trap	42.1*	5.43	13

* - Not significantly different at $P < 0.05$

Walleye sampled in 1990 were aged using otoliths. The scale samples collected were discarded as they were impossible to age with any degree of confidence. The mean age obtained from 24 otoliths was 7.6 years. The age composition of walleye sampled in 1990 is shown in Figure 17. The youngest

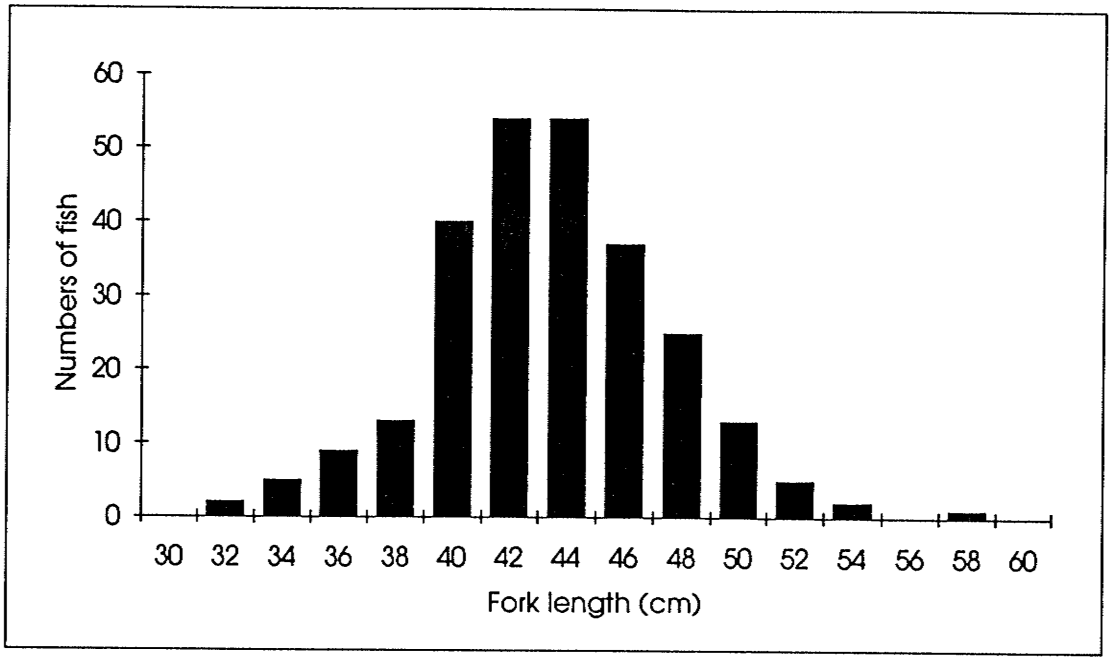


Figure 16. Length distribution of walleye sampled at the fishway cage in 1990.

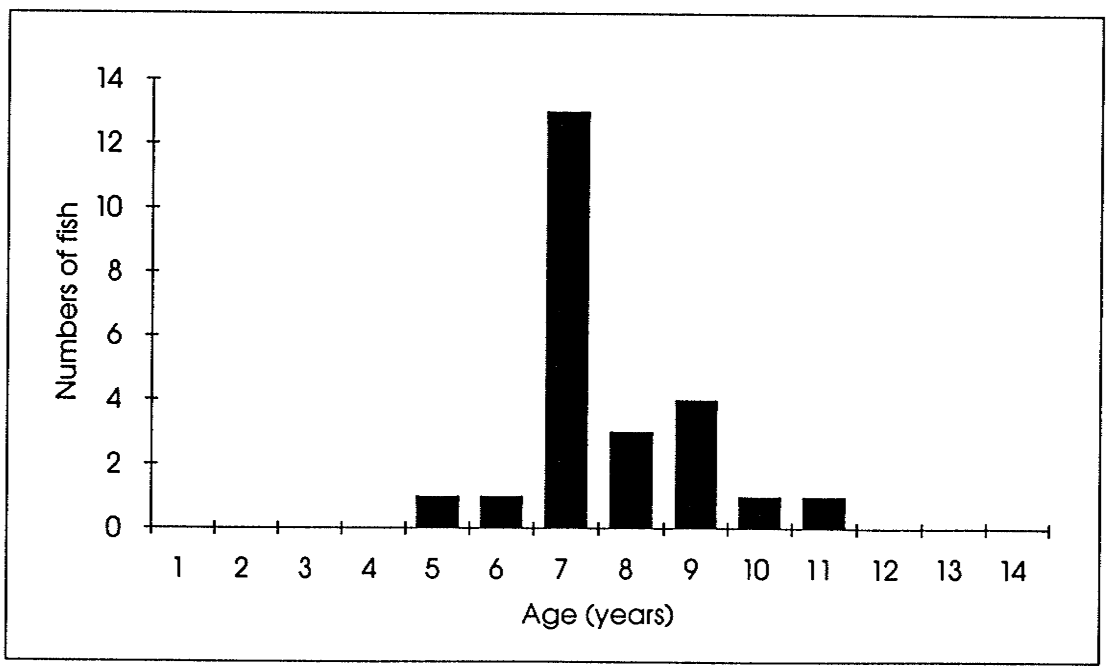


Figure 17. Age composition of walleye sampled at the fishway cage in 1990.

mature male and female walleye in the spawning run were seven years of age. Most seven year old females were not sexually mature however.

Eighteen walleye, of 110 tagged in 1990 and 1991, were recaptured and reported by anglers and commercial fishermen (Appendix 2). This represents an overall minimum harvest rate of 16.4% of tagged walleye (Table 7).

Table 7. Recapture of tagged walleye by anglers and commercial fishermen.

Tagging location	Year	Number tagged	Number recaptured	Recapture rate (percent)
Fishway cage	1990	78	9 (12)*	11.5 (15.4)*
Below dam	1990	13	3	23.1
Fishway cage	1991	19	3	15.8
Total		110	15 (18)*	13.6 (16.4)*

* - Three tagged walleye were reported caught by a commercial fishermen in 1990, however the tag numbers were not recorded. They have been assigned to the fishway cage tagging location as most walleye were tagged there.

The rate of tagged walleye recapture was not significantly different among the three tagging locations and years, regardless of whether the three walleye for which tag numbers were unavailable were included in the analysis or not (test for population proportions, $P < 0.05$).

Although 12, and possibly 15, of the recaptured walleye were tagged after ascending the fishway and released into Cowan Lake, only one was caught there. The rest were recaptured downstream of Cowan Dam. On average, the walleye were recaptured 130 km from Cowan Dam about 50 days after being tagged. The walleye at large the least amount of time prior to recapture traveled 64 km in seven days (9.1 km/day). The walleye at large the longest was recaptured about 220 km from Cowan Dam in Lac Ile-a-la-Crosse, 537 days after being tagged. Figure 18 shows the distribution of tagged walleye recapture locations.

Although thirteen walleye were tagged at the downstream trapping site in 1990, no population or percent passage estimates could be made since no tagged walleye were recaptured after ascending the fishway.

White sucker: Although peak white sucker movement occurred over only three days (May 20-22), substantial numbers of suckers ascended the fishway on almost every day of operation (Figure 9). During the peak three day period, 41.3% (1666) of white suckers ascended the fishway. Peak movement coincided with a daily average fishway water temperature of 13.0°C. White suckers were the only species to ascend the fishway prior to the late April blizzard.

Over the total 1990 monitoring period, 29% (620) of the white suckers that ascended the fishway were in pre-spawning condition, 70% (1476) were spent, and 1% (24) were immature. The spawning condition of white suckers changed over the course of fishway monitoring. At the beginning of monitoring, 100% of male and female white suckers were in pre-spawning condition. The first spent males were observed on May 12, and the proportion of spent males continued to increase until May 28 at which time all were spent. White sucker movement through the fishway peaked on May 20 when 771 fish were captured in the fishway trap. Forty-six percent of ascending males were still in ripe spawning condition and 54% were spent at this time (Figure 19). The change in condition

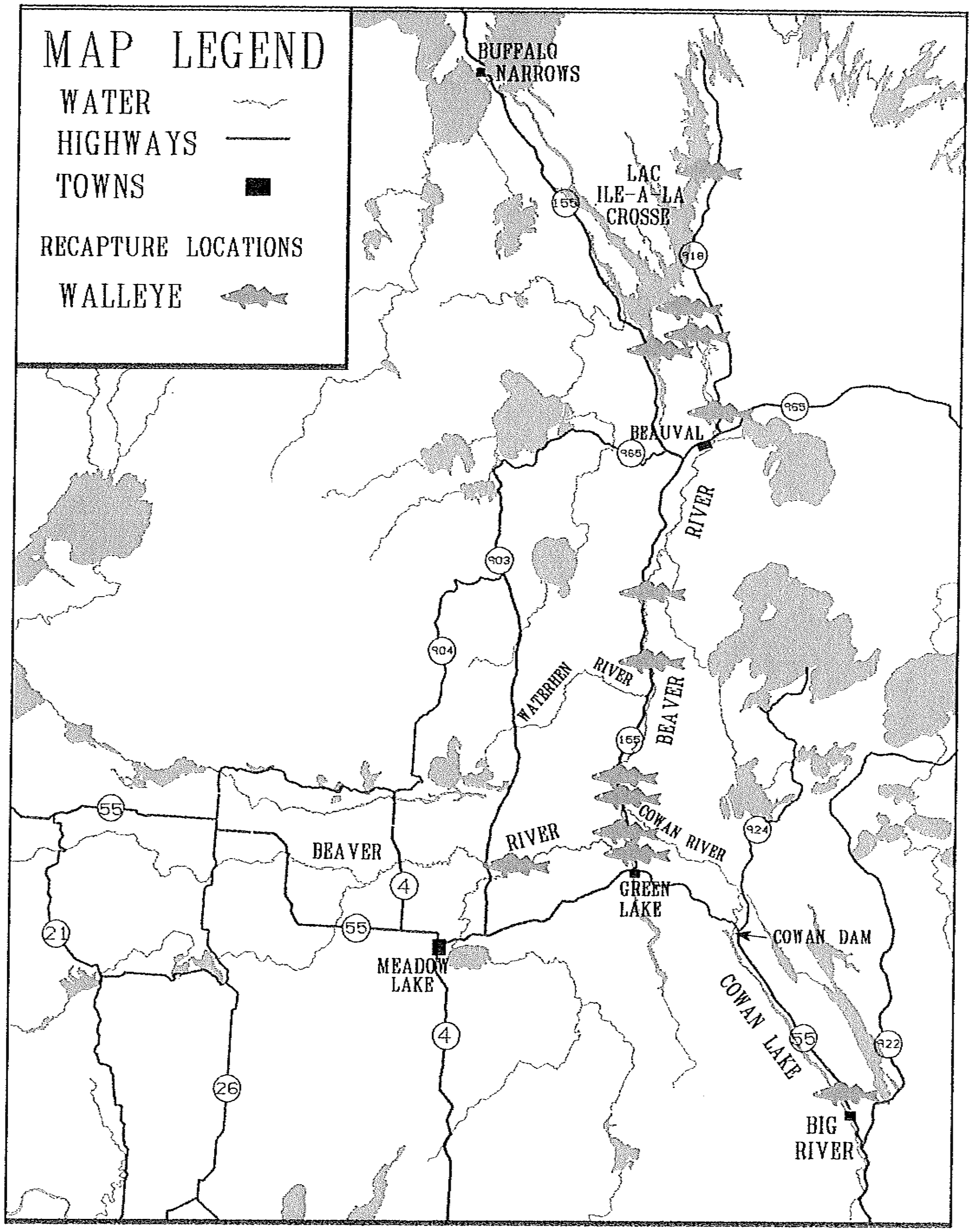


Figure 18. Distribution of tagged walleye recapture locations.

from pre-spawning to spent occurred earlier in females than it did in males. By the time white sucker movement peaked on May 20, 90% of females ascending the fishway were already spent. Virtually all females were spent by May 23 (Figure 20).

Peak white sucker movement through the fishway occurred between 1530 hours and 1900 hours (daily cage lift 3). The next greatest rate of passage occurred between 0930 hours and 1500 hours (cage lift 2). The time of day with the lowest rate of passage was the period between 1930 hours and 0900 hours the following day (cage lift 1) (Figure 10).

The length - weight relationship of 1128 white suckers captured at the fishway cage in 1990 was $W = 0.0359\ L^{2.7429}$. The length distribution of white suckers captured in the fishway cage is shown in Figure 21. White suckers sampled in the tailwater pool were significantly longer than white suckers captured at the downstream trap. However, there was no significant difference between mean white sucker lengths from the fishway cage and the tailwater pool (Table 8).

Spent female white suckers at the time of ascending the fishway were longer than females that ascended prior to spawning. Although spent females were longer than spent males, the length of pre-spawn females was not significantly different from pre-spawn males (Table 9). The mean length of both pre-spawning and spent female white suckers captured at the fishway cage declined over the course of the 1990 monitoring period (Figures 22 & 23). The mean length of pre-spawning and spent male white suckers did not exhibit a similar decrease over time.

A few (three to five) of the 139 white suckers tagged at Cowan Dam in 1990 were reportedly caught by Lac Ile-a-la-Crosse commercial fishermen where

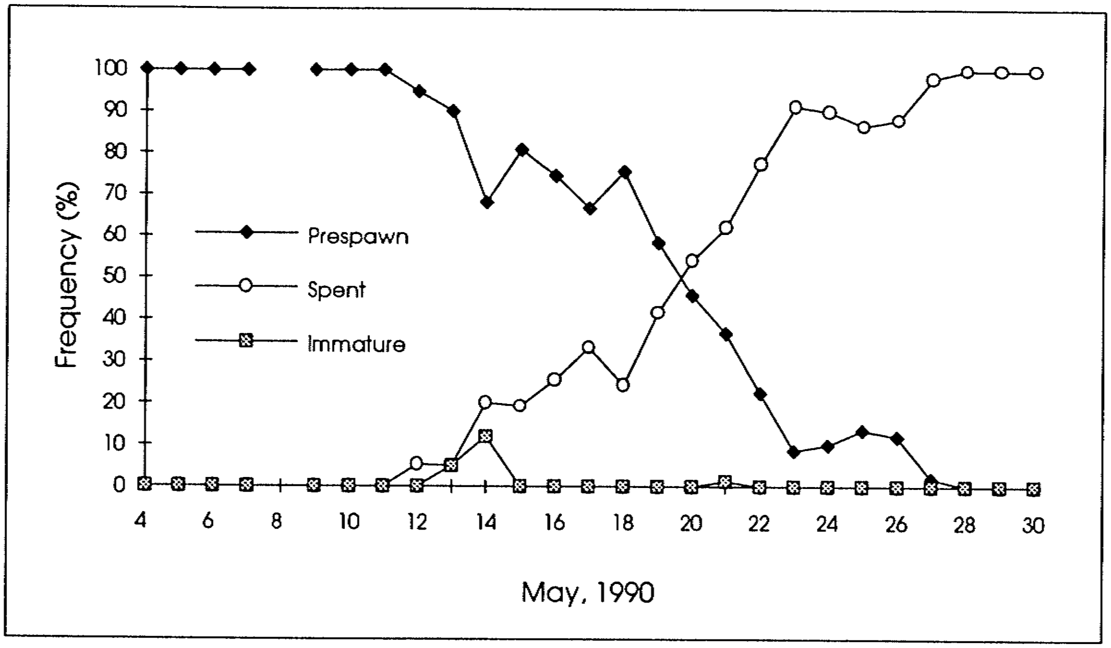


Figure 19. Temporal changes in spawning condition of male white suckers sampled at the fishway cage in 1990.

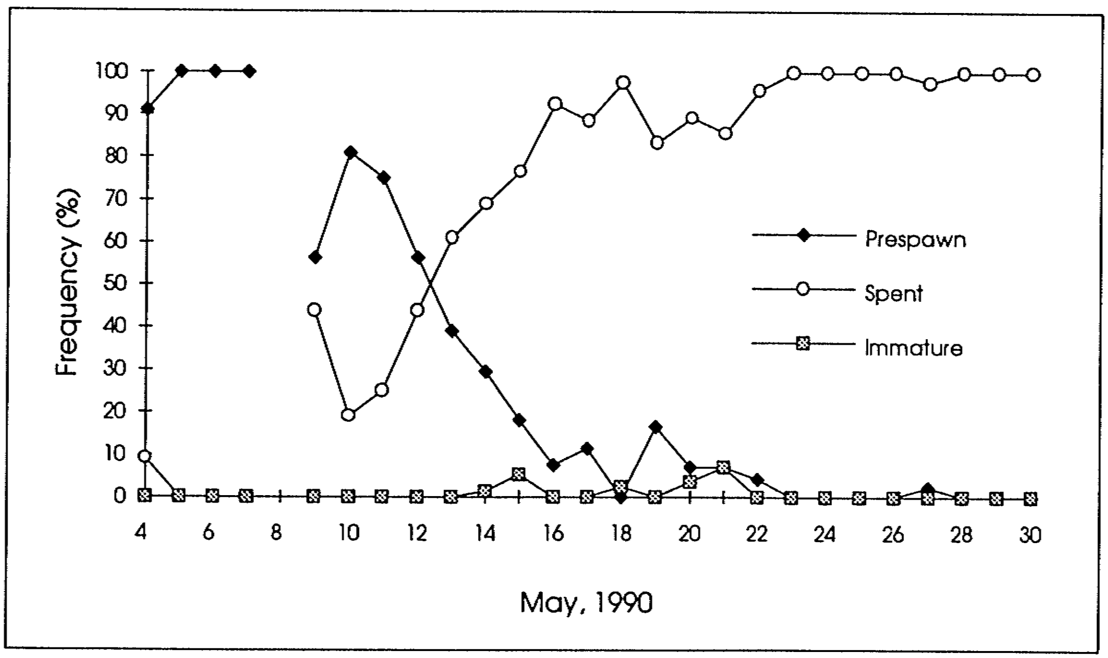


Figure 20. Temporal changes in spawning condition of female white suckers sampled at the fishway cage in 1990.

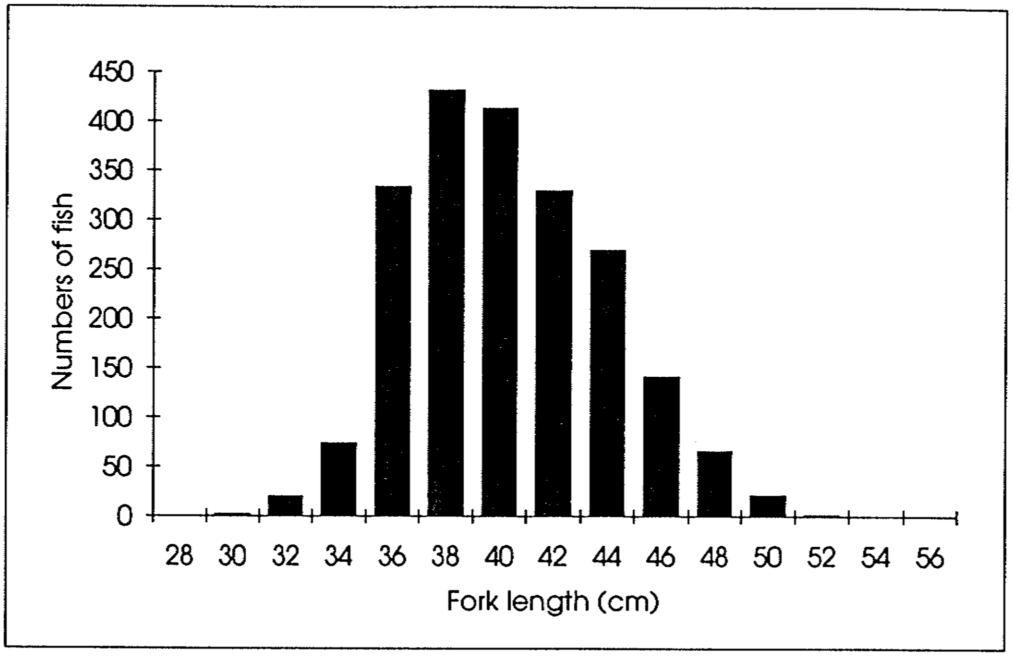


Figure 21. Length distribution of white suckers sampled at the fishway cage in 1990.

Table 8. Mean fork lengths (cm) of white suckers sampled at Cowan Dam in 1990.

Location	Mean length	Standard deviation	Number of fish
Fishway cage	41.2	3.62	2105
Downstream trap	40.1*	2.88	98
Tailwater pool	42.5*	3.40	50
Below dam Combined	40.9	3.26	148

* - Significantly different at P < 0.01

Table 9. Comparison of mean fork lengths (cm) between pre-spawn and post-spawn white suckers sampled at the fishway cage in 1990.

	Pre-spawn			Post-spawn		
Sex	Mean length	Standard deviation	n	Mean length	Standard deviation	n
Male	39.36	1.077	22	40.86[b]	1.281	17
Female	40.88[a]	1.048	17	43.33[a,b]	2.063	20

a - Pre-spawn and post-spawn females have significantly different (P < 0.05) mean fork lengths.
b - Post-spawning males and females have significantly different (P < 0.05) mean fork lengths.

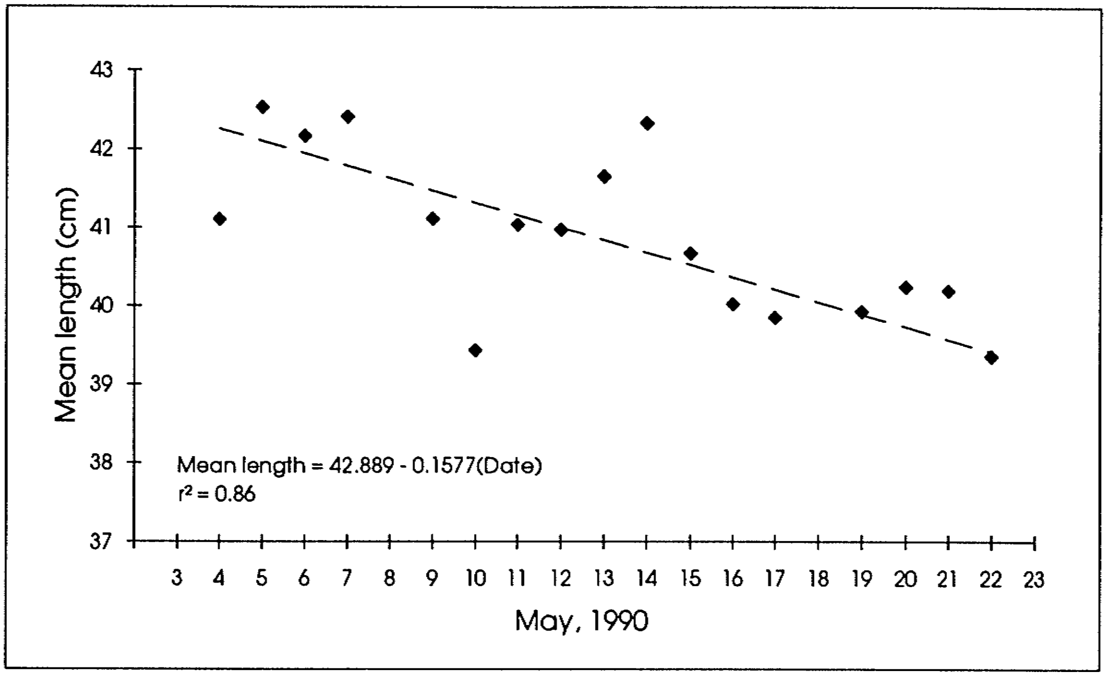


Figure 22. Trend in pre-spawning female white sucker mean length during the 1990 monitoring period.

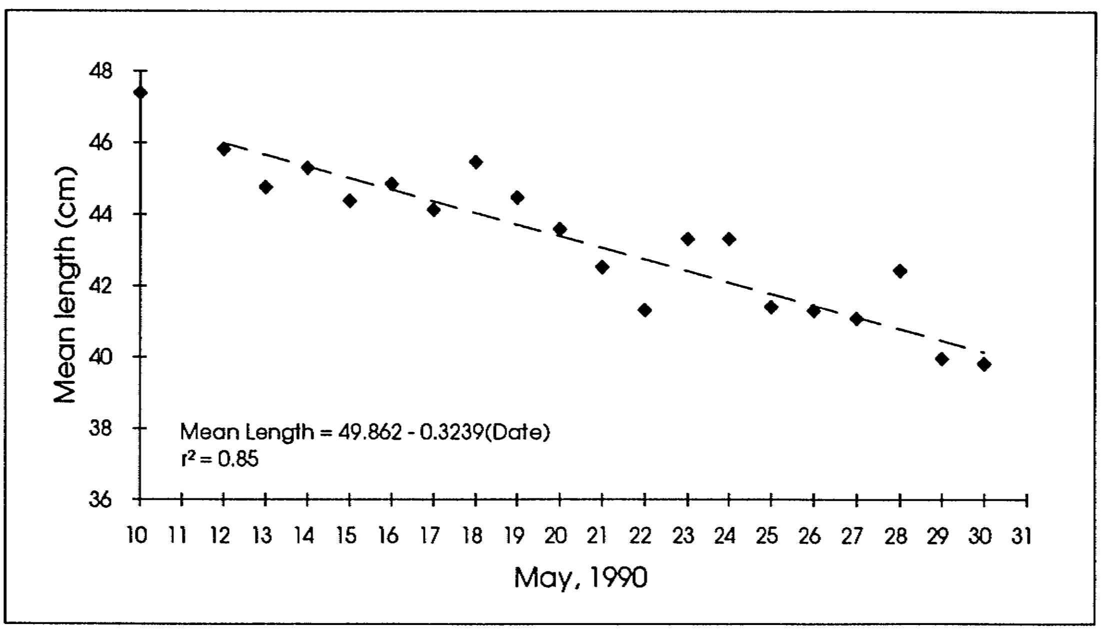


Figure 23. Trend in spent female white sucker mean length during the 1990 monitoring period.

the Beaver River enters the lake. They were caught 30 to 50 days after being tagged, almost 190 km from Cowan Dam. Because no tag numbers were reported, it is unknown whether they were tagged below Cowan Dam or at the fishway cage after ascending the fishway.

Fifty-six tagged white suckers were recaptured in the fishway cage in 1990. A higher proportion of white suckers tagged in the tailwater pool passed through the fishway than did white suckers tagged at the downstream trap (Table 10).

Table 10. Summary of white sucker tagging in 1990, and movement through the fishway.

Tagging location	Number caught	Number tagged	Number of recaptures at fishway
Downstream trap	98	89	27*
Tailwater pool	50	50	29*
Total	148	139	56

* - Significantly different from expected numbers if tagged fish ascended with equal likelihood from each site (G test, $P < 0.05$).

The ratio of male to female white suckers captured at the fishway cage was 1:1. Of 1811 known sex white suckers, 905 were male and 906 were female. The sex ratios of white suckers tagged at the down-stream trap and in the tailwater pool were not significantly different from the sex ratios of tagged white suckers that ascended the fishway from each of the tagging sites. The mean lengths of tagged white suckers that ascended the fishway, and the mean lengths of the populations of white suckers tagged at the downstream trap and tailwater pool locations did not differ significantly.

White suckers tagged in the tailwater pool ascended the fishway significantly sooner after tagging than did white suckers tagged at the downstream trap (Figure 24) (G test, $P < 0.05$). Those tagged at the downstream trap waited an average of 13.9 days between being tagged and ascending the fishway, while those tagged in the tailwater pool waited only 5.2 days.

Of 4031 white suckers examined for tags at the fishway cage, 29 of 50 white suckers tagged in the tailwater pool were recaptured. Based on this recapture rate, it is estimated that the tailwater pool contained a population of 6854 white suckers. Lower and upper 95% confidence intervals of the estimated population size are 4821 and 9707 individuals respectively. The 4031 white suckers that ascended the fishway represent a passage rate of 58.8 percent of an estimated population size of 6854. Lower and upper 95% confidence intervals for estimated passage were 41.5% and 83.6% respectively.

Longnose sucker: In 1990, almost 95% of longnose suckers ascended the fishway during a seven day period in early May (Figure 9). Fish passage commenced when the daily average fishway water temperature reached 6.8°C, and peaked when it reached 8.0°C. Almost 98% of longnose suckers that ascended the fishway in 1990 did so prior to spawning. The remainder were either spent or immature. Peak longnose sucker movement through the fishway occurred between 1530 hours and 1900 hours (daily cage lift 3)(see Figure 25). The next greatest rate of passage occurred between 0930 hours and 1500 hours (cage lift 2). The lowest rate of passage occurred during the period between 1930 hours and 0900 hours the following day (cage lift 1).

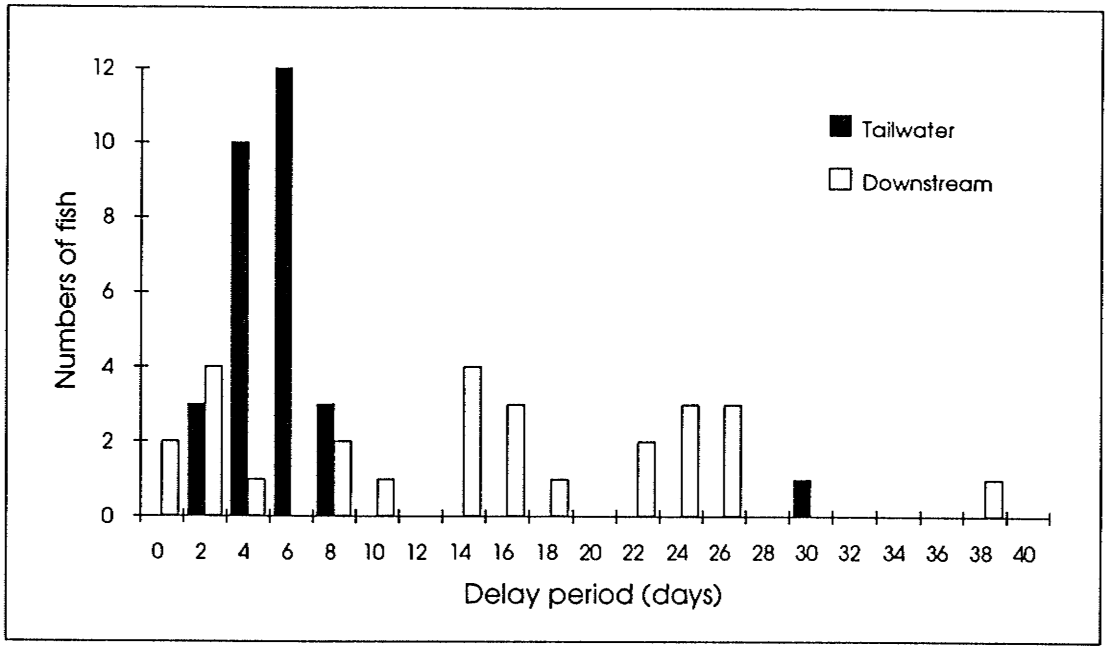


Figure 24. Delay periods in 1990, between tagging white suckers at the downstream trap and in the tailwater pool, and their recapture after ascending the fishway.

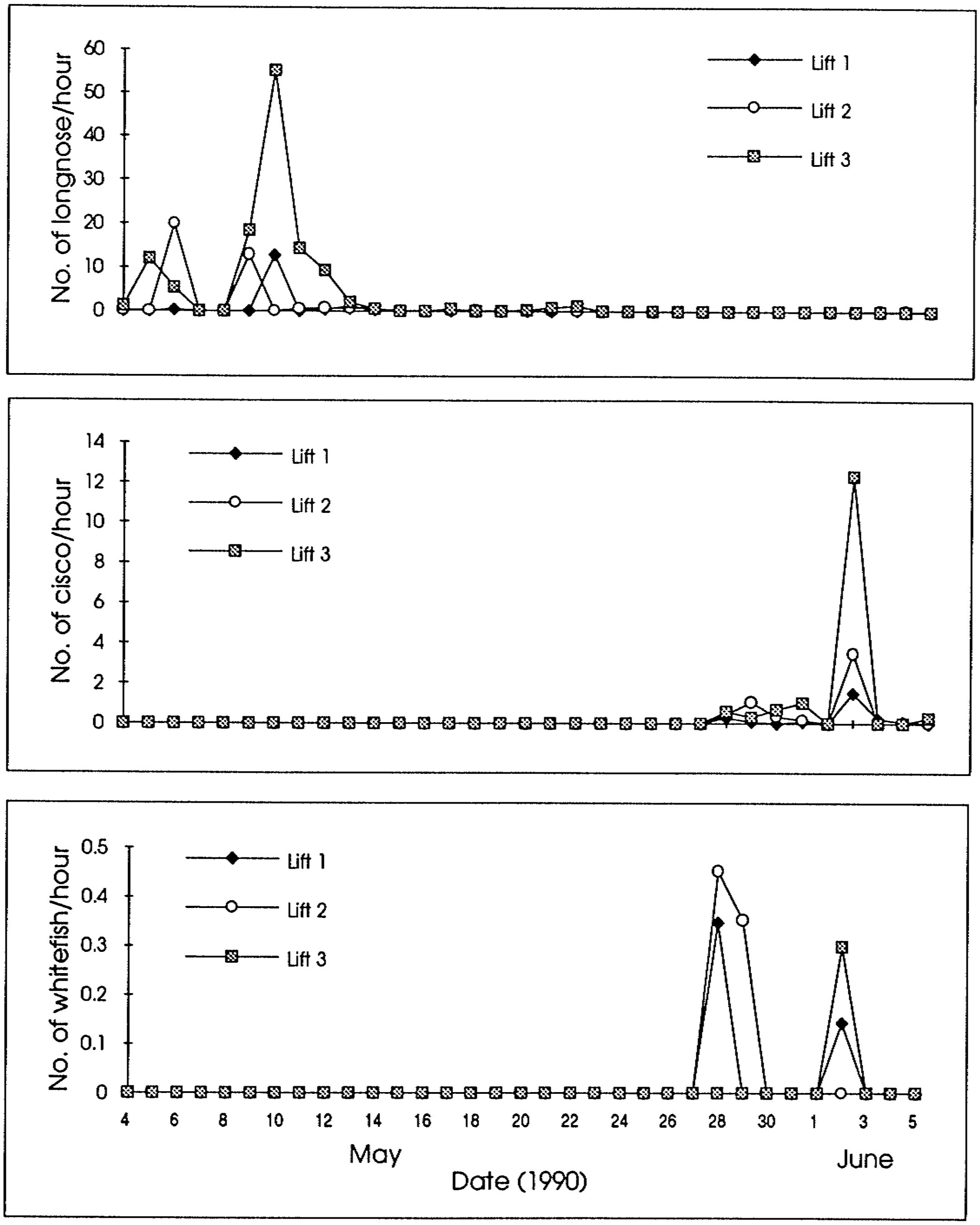


Figure 25. Diurnal movement of longnose suckers, cisco and whitefish.

The length - weight relationship of 242 longnose suckers captured at the fishway cage in 1990 was $W = 0.0090\ L^{3.1259}$. The length distribution of longnose suckers captured in the fishway cage is shown in Figure 26. Males were significantly shorter on average than females (t-test, $P < 0.001$). Longnose suckers captured at the fishway cage were significantly longer than those captured at the two tagging sites below the dam (Table 11).

A total of five longnose suckers were tagged at the downstream trap and in the tailwater pool in 1990. No population or percent passage estimates could be made since none of the marked fish were recaptured at the fishway exit cage.

Table 11. Mean fork lengths (cm) of longnose suckers sampled at Cowan Dam in 1990.

Location	Mean length	Standard deviation	Number of fish
Fishway cage	44.6*	3.91	443
Downstream trap	37.2	1.25	4
Tailwater pool	38.1	-	1
Below dam Combined	37.3*	1.16	5

* - Significantly different at $P < 0.01$

Cisco: A total of 113 cisco utilized the fishway during the latter days of fishway monitoring in 1990 (Figure 9). Although cisco ascended the fishway on eight separate days, 72.6% (82) ascended on June 2. Daily average fishway water temperature was 16.7°C that day. Peak cisco movement through the fishway occurred between 1530 hours and 1900 hours (daily cage lift 3) (see Figure 25). The next greatest rate of passage occurred between 0930 hours and 1500 hours

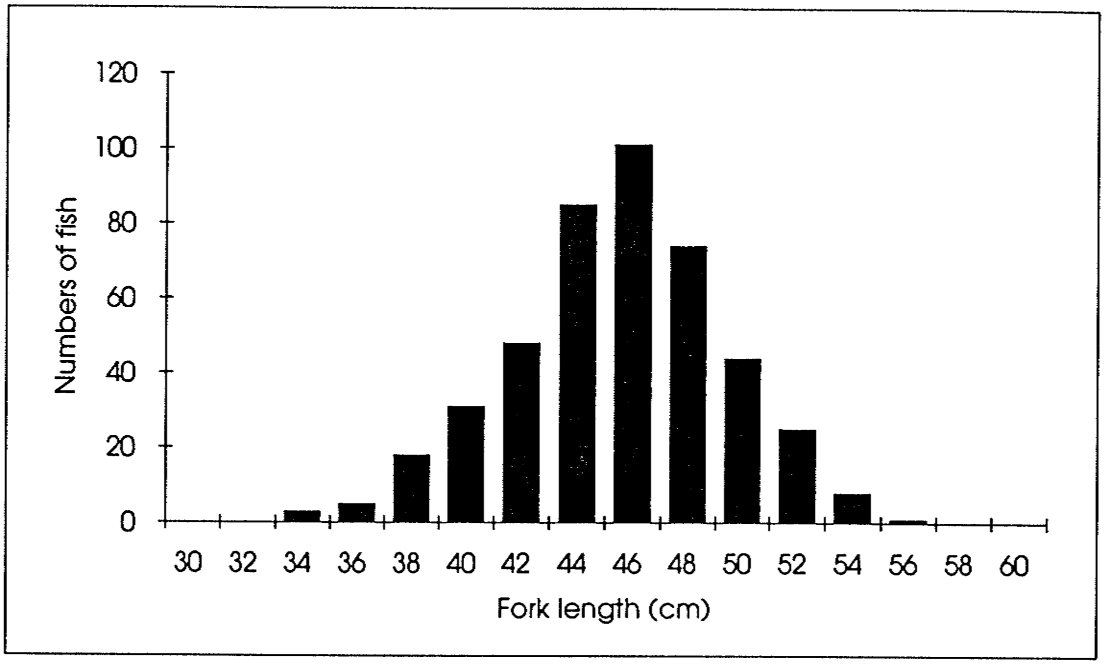


Figure 26. Length distribution of longnose suckers sampled at the fishway cage in 1990.

(cage lift 2). The lowest rate of passage occurred during the period between 1930 hours and 0900 hours the following day (cage lift 1). The length distribution of cisco captured in the fishway cage is shown in Figure 27. The mean length of the 113 cisco sampled was 28.5 cm (standard deviation of 1.38 cm). The length - weight relationship was $W = 0.0099\ L^{3.1294}$; n = 71.

A total of 69 cisco sampled in 1990 were aged using both scales and otoliths. The mean age of scale and otolith aged cisco was 7.2 and 7.7 years, respectively. The age distribution for otolith aged cisco is shown in Figure 28.

Lake whitefish: Few lake whitefish ascended the fishway during the latter days of fishway monitoring (Figure 9). Seven of twelve whitefish (58.3%) ascended on May 28 when daily average fishway water temperature reached 19.8°C. The rate of whitefish movement through the fishway did not change significantly over the course of the day (Figure 25).

The length distribution of whitefish captured in the fishway cage is shown in Figure 29. The mean length of the 12 whitefish sampled was 36.1 cm (standard deviation of 2.03 cm). The length - weight relationship was $W = 0.0234\ L^{2.8684}$; n = 12.

A total of 10 whitefish sampled in 1990 were aged using both scales and otoliths. The mean age of scale and otolith aged whitefish was 8.5 and 8.8 years, respectively. The age distribution for whitefish aged using otoliths is shown in Figure 30.

Fishway hydraulic conditions

Water surface profiles within the fishway are illustrated in Figures 31 and 32. These profiles represent the highest and lowest water levels recorded near

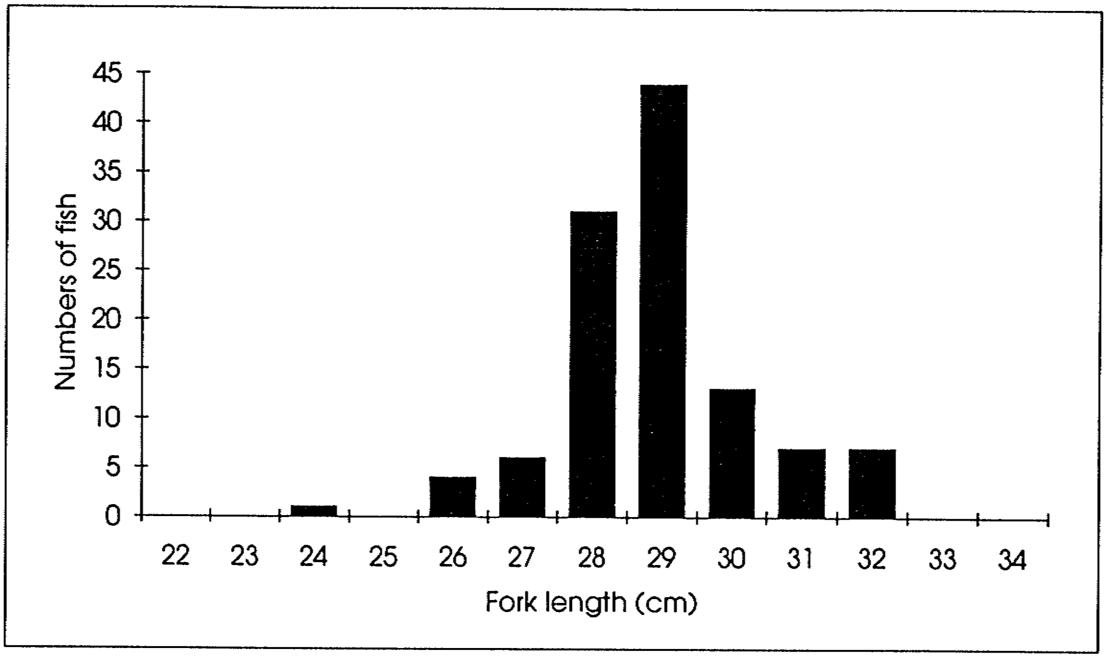


Figure 27. Length distribution of cisco sampled at the fishway cage in 1990.

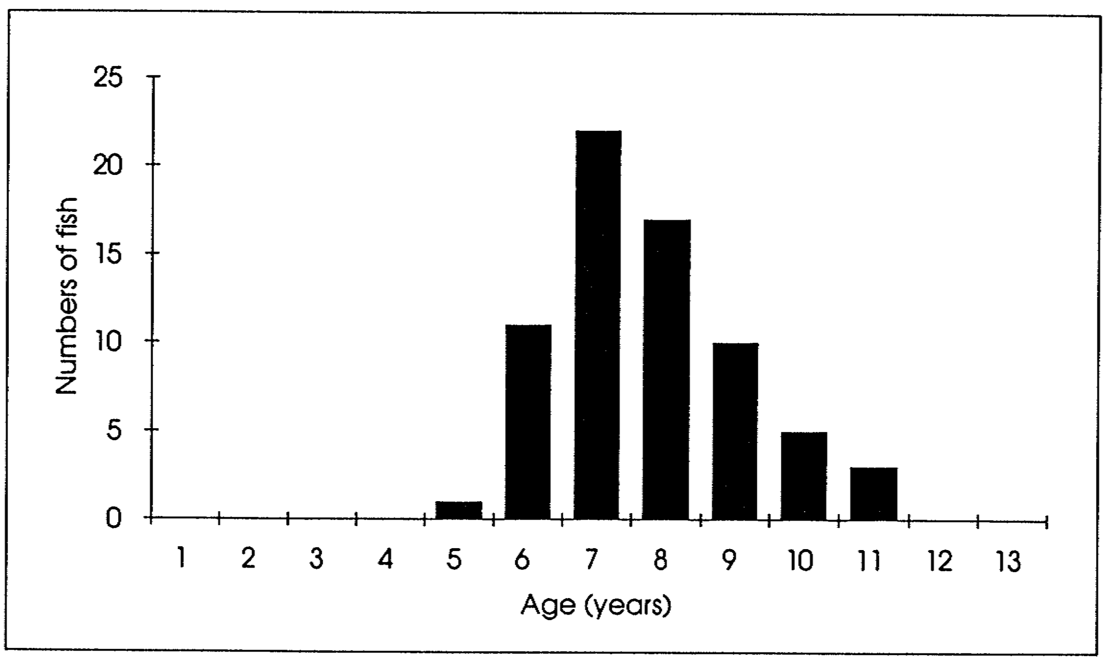


Figure 28. Age composition of cisco sampled at the fishway cage in 1990.

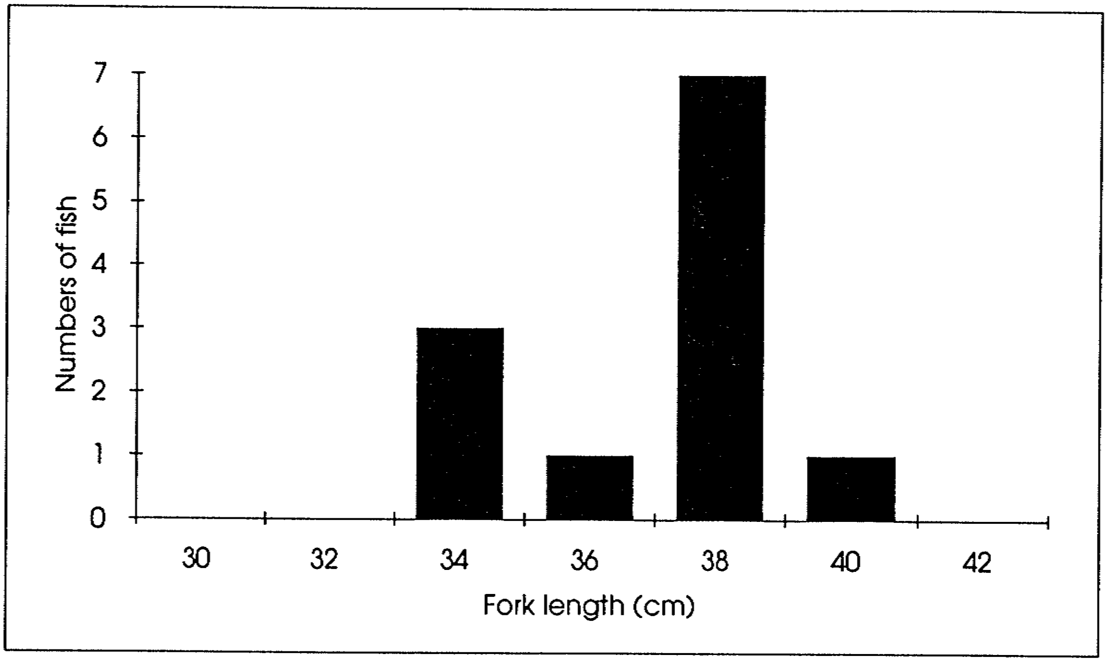


Figure 29. Length distribution of lake whitefish sampled at the fishway cage in 1990.

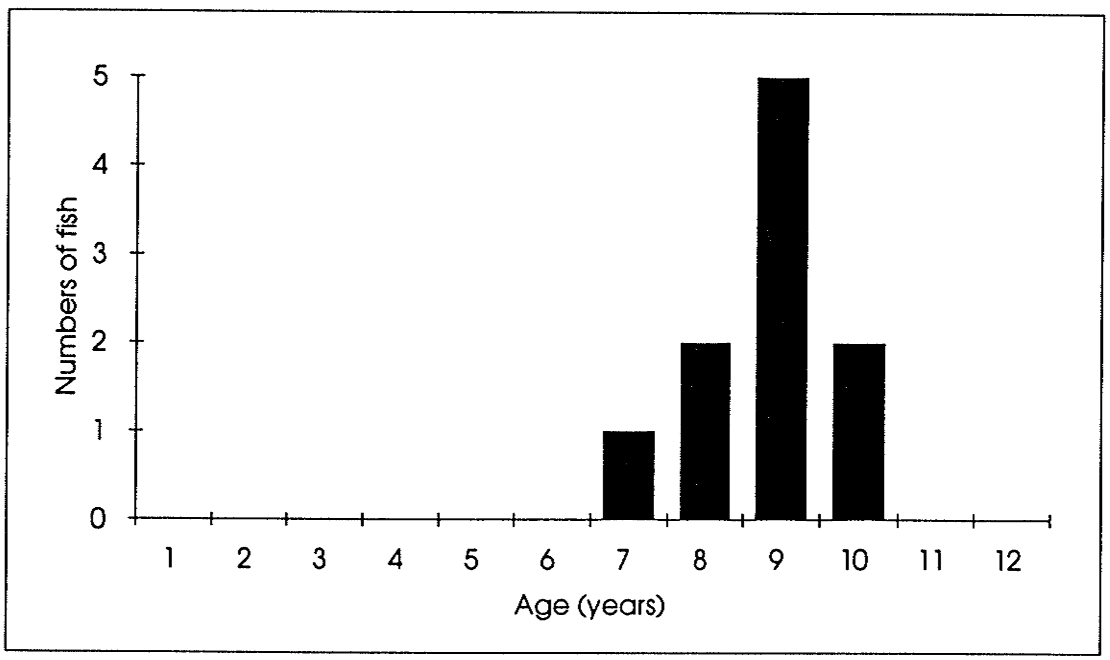
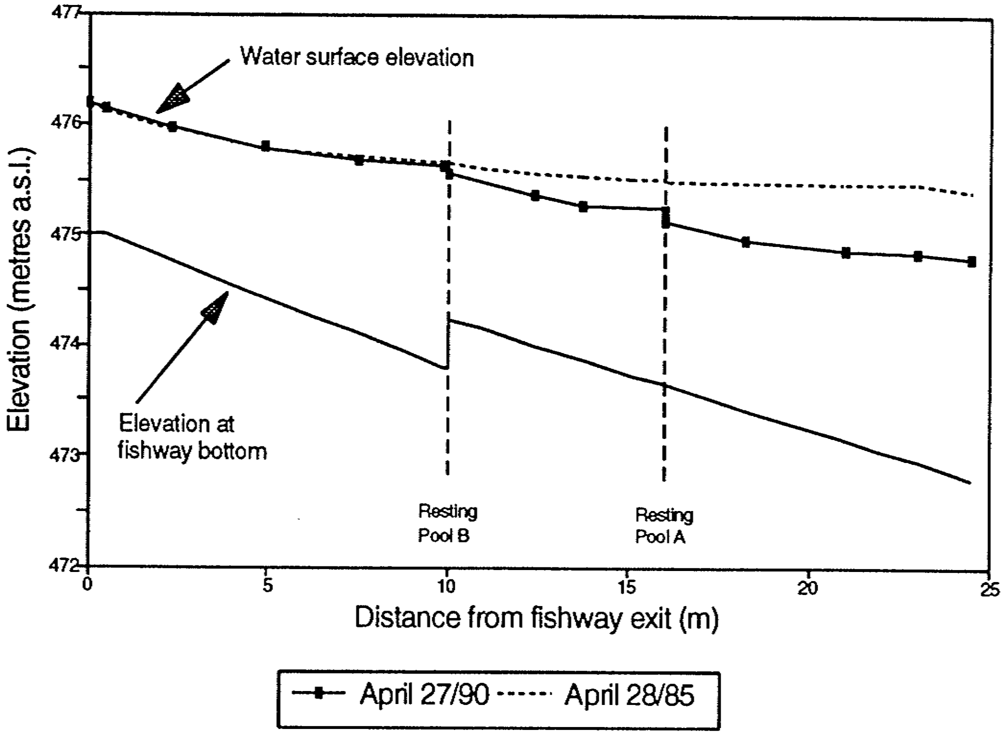
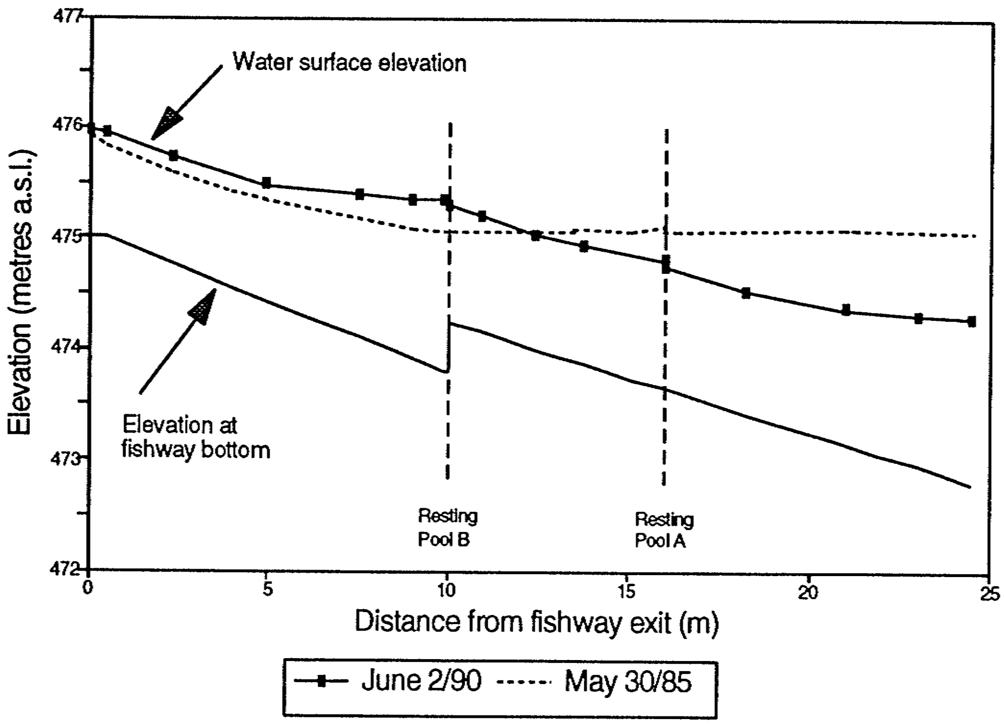


Figure 30. Age composition of lake whitefish sampled at the fishway cage in 1990.





Figures 31 and 32. Fishway water surface profiles representing the highest and lowest water levels experienced in the fishway in 1985 and 1990.

the fishway exit during the 1990 evaluation period. The 1985 profiles are included for comparison. In 1990, the greatest water depth recorded near the fishway exit was 1.096 m, and the least, 0.881 m.

Fish were forced to navigate all three fishway chutes to ascend the fishway in 1990, 1991 and 1992 due to below average runoff and low tailwater levels. In 1985, when spring runoff was greater, tailwater levels were sufficiently high to allow fish to ascend the fishway via the single upper chute (Table 12).

Table 12. Hydraulic head (metres) and estimated peak flow frequency differences for the four fishway study years.

Study year	Maximum hydraulic head	Minimum hydraulic head	Mean hydraulic head	Estimated peak flow frequency*
1985	1.276	0.465	0.837	1 : 10
1990	1.828	0.863	1.300	1 : 1.3
1991	1.793	1.203	1.464	1 : 0.6
1992	1.963	1.593	1.751	1 : 0.5

* - Peak flow frequency estimates were obtained from the Saskatchewan Water Corporation for the two nearest gauging stations in the Beaver River watershed. These stations are located on the Beaver River below its confluence with the Waterhen River, and at Norbury Creek, a small intermittent stream in the extreme southern part of the Cowan Lake watershed. The average of the peak flow frequency estimate from both stations was used to approximate the estimated peak flow frequency at Cowan Dam.

During the 1990 monitoring period, Cowan Lake was held near FSL by adjusting the dam control gates to vary the amount of water being discharged. Tailwater elevation and hydraulic head variations are shown in Figures 33 and 34. Water depths within the fishway and the fishway discharge rate both declined steadily during early May, increased slowly from May 10 to May 23, and

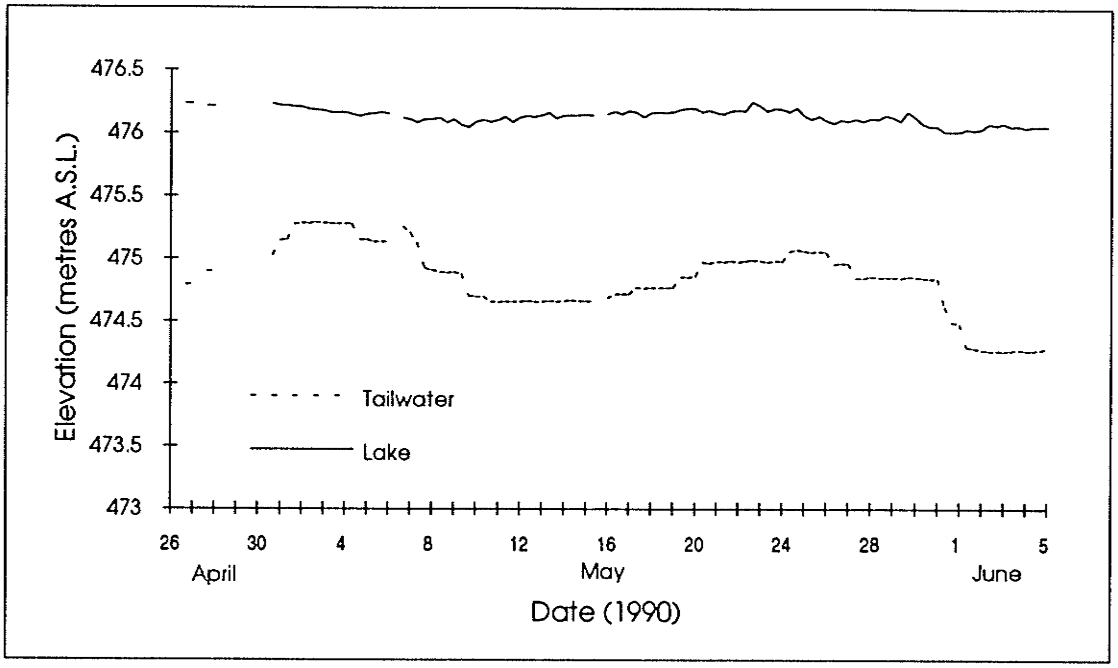


Figure 33. Temporal changes in lake and tailwater elevations during the 1990 monitoring period.

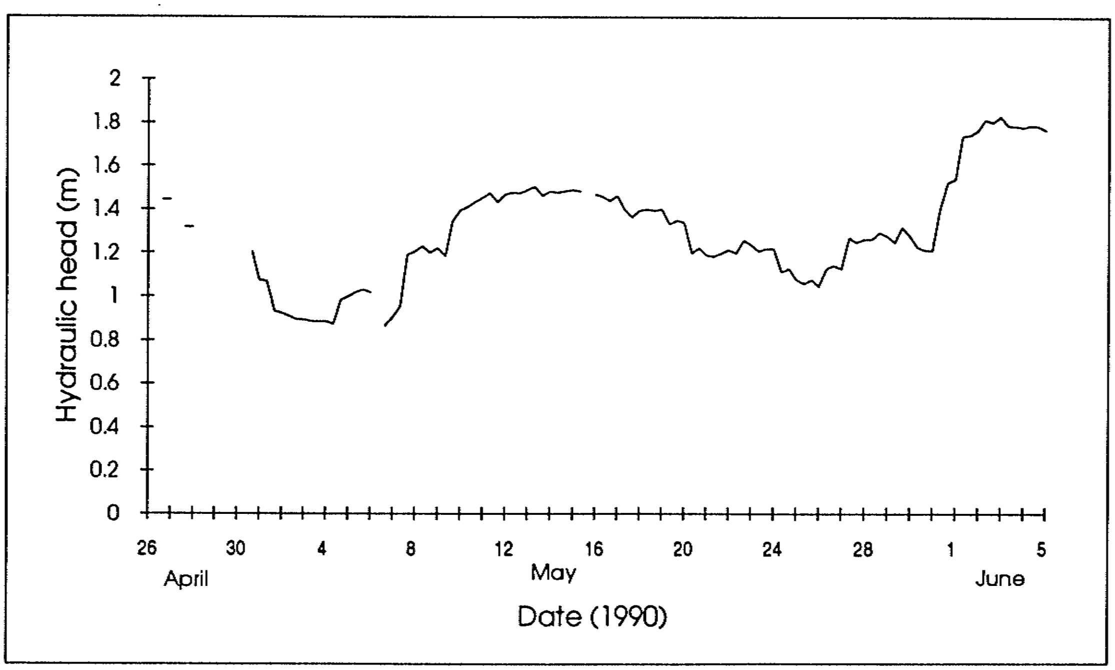


Figure 34. Temporal changes in hydraulic head during the 1990 monitoring period.

then declined again. The period of decline following May 23 was marked by a dramatic drop in both fishway water depth and discharge on May 30 and June 1, due to large quantities of ivy-leaved duckweed, *Lemna trisulca*, and filamentous algae, *Cladophora* sp., plugging the mesh of the fishway cage and blocking off most of the fishway flow (Figure 35).

Fishway water velocities followed the same trends over time as were observed for fishway water depth and discharge. Water velocities at 60% of fishway water depth ranged from 1.6 m/s near the start of the monitoring period to 1.2 m/s near the end. Velocities at 20% of depth ranged from 0.85 to 0.65 m/s over the same period (Figure 36).

Fish passage and fishway hydraulic conditions

General: In 1990, no significant relationship was found between the movement of walleye, longnose suckers, cisco or whitefish, and any of the fishway hydraulic parameters analyzed.

Northern pike: Northern pike were the only species that exhibited a significant relationship between numbers of fish ascending the fishway during the period of peak fish movement and water velocities in the fishway. At station C, for the main period of pike movement (May 21 - June 5, 1990), pike numbers appeared to decrease as fishway water velocities at 60% of fishway water depth increased (Figure 37). The slope of this regression was found to be significant ($P < 0.05$), although it is quite weak ($r^2 = 0.27$). No relationship was found when pike movement and water velocities were regressed over the entire monitoring period.

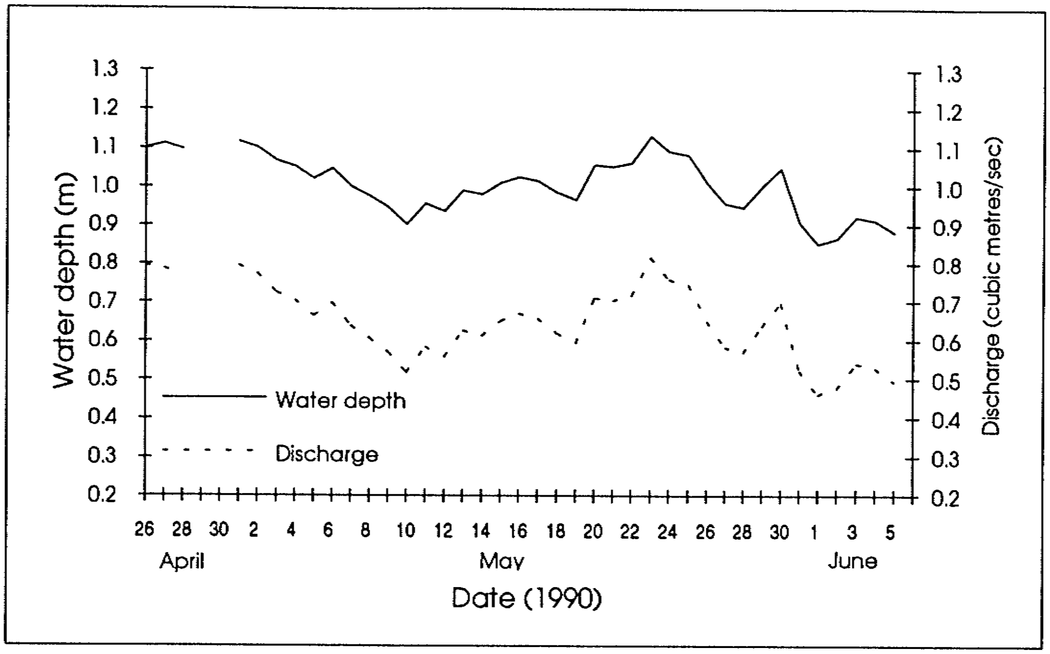


Figure 35. Temporal changes in fishway depth and discharge at measuring station C of Cowan Dam in 1990.

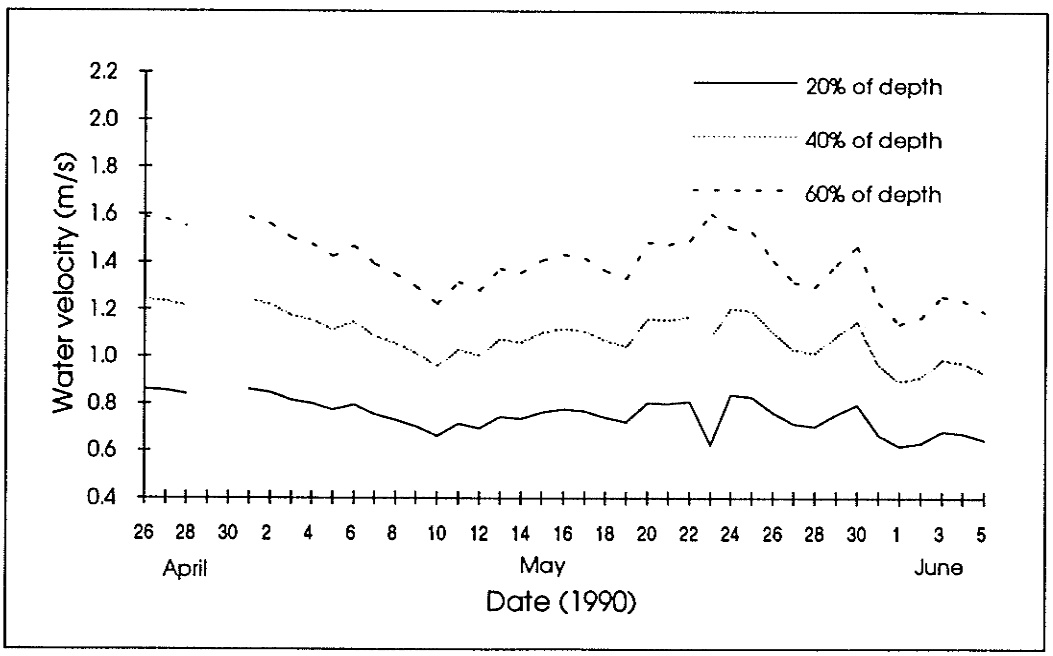


Figure 36. Temporal changes in fishway velocities at 20%, 40% and 60% of fishway water depth in 1990.

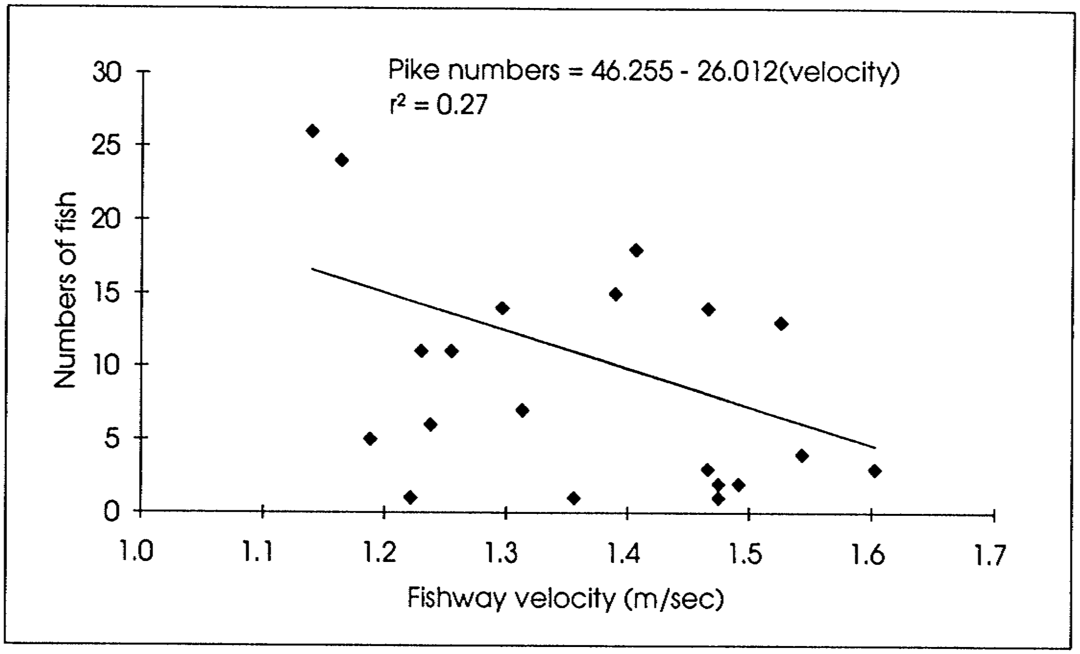


Figure 37. Regression of northern pike movement and water velocity at 60% of fishway water depth.

Changes in daily mean length of northern pike captured at the fishway cage were analyzed against estimated fishway water velocities at 20%, 40% and 60% of the fishway water depth at fishway measuring station C. The average fork length of pike ascending the fishway was found to increase as estimated fishway velocities at 40% and 60% of fishway water depth increased (Figures 38 and 39). No relationship was found for daily mean length and estimated water velocity at 20% of the fishway water depth.

Northern pike movement was not related to attraction flows, nor to differences in total hydraulic head between lake and tailwater levels.

<u>White sucker</u>: Changes in daily mean lengths of pre-spawning and spent female white suckers, were analyzed against estimated fishway water velocities at 20%, 40% and 60% of the water depth within the fishway at measuring station C. No significant relationship between mean length and estimated water velocity at any depth was found for pre-spawning female white suckers. However, significant, though weak, relationships were found for mean length of spent female white suckers and estimated water velocities at 40% and 60% of fishway water depth at fishway measuring station C. The average fork length of spent female white suckers was found to decrease as estimated fishway velocities increased (Figures 40 and 41). Mean length of spent female white suckers was not found to be related to fishway water velocity at 20% of depth.

White sucker movement was not found to be related to attraction flows, nor to differences in total hydraulic head between lake and tailwater levels.

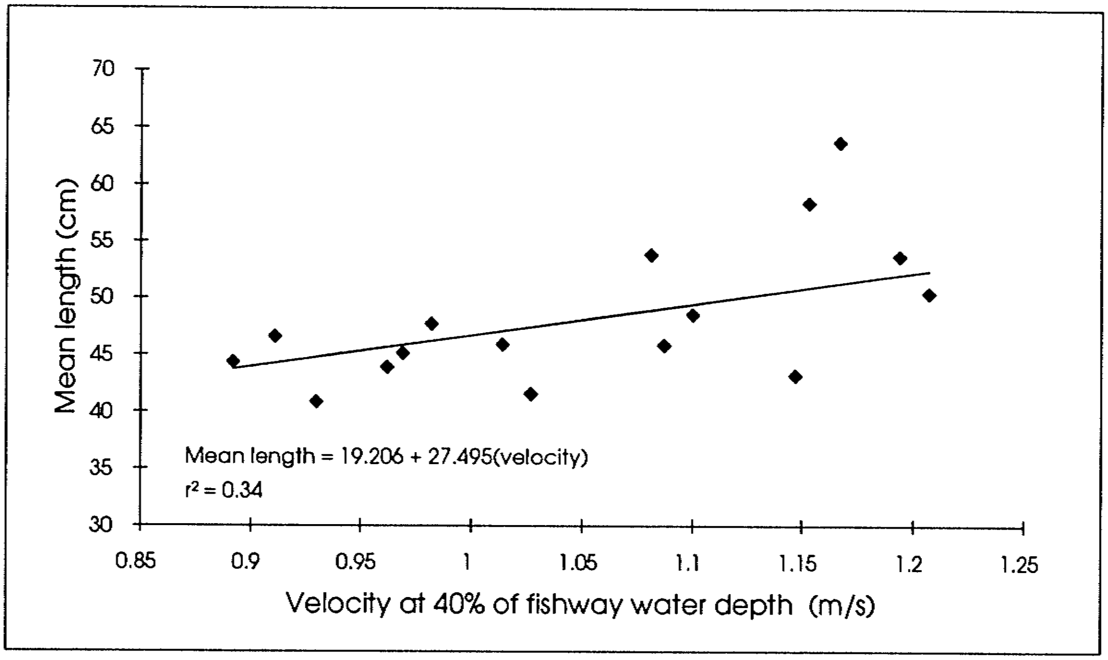


Figure 38. Regression of northern pike mean length and water velocity at 40% of fishway water depth.

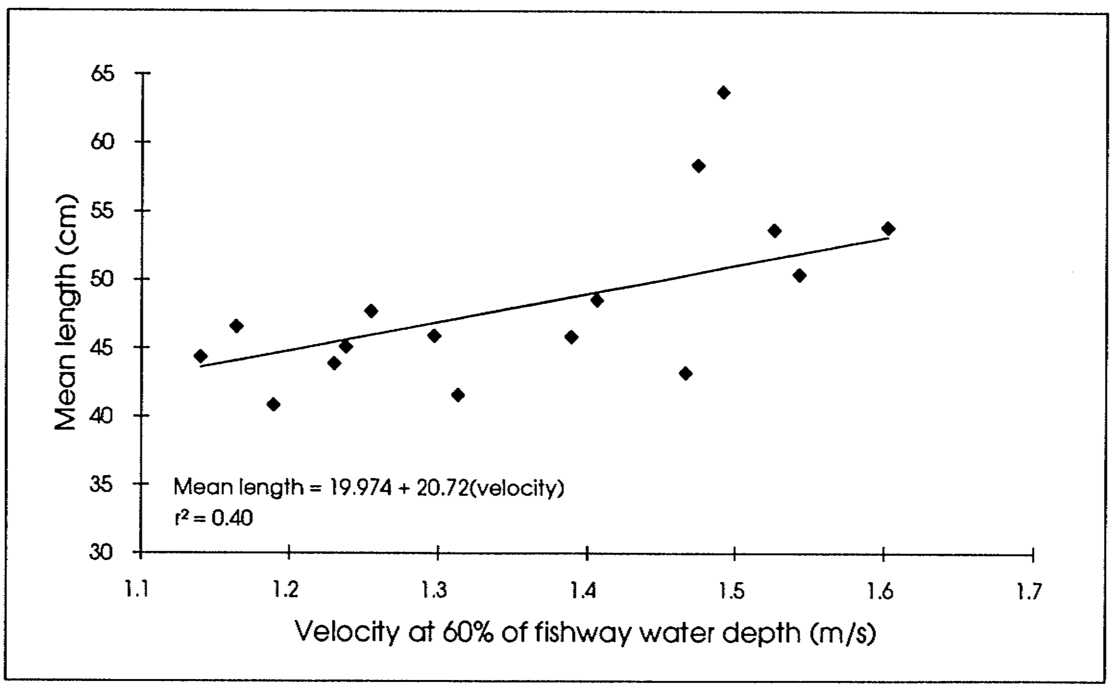


Figure 39. Regression of northern pike mean length and water velocity at 60% of fishway water depth.

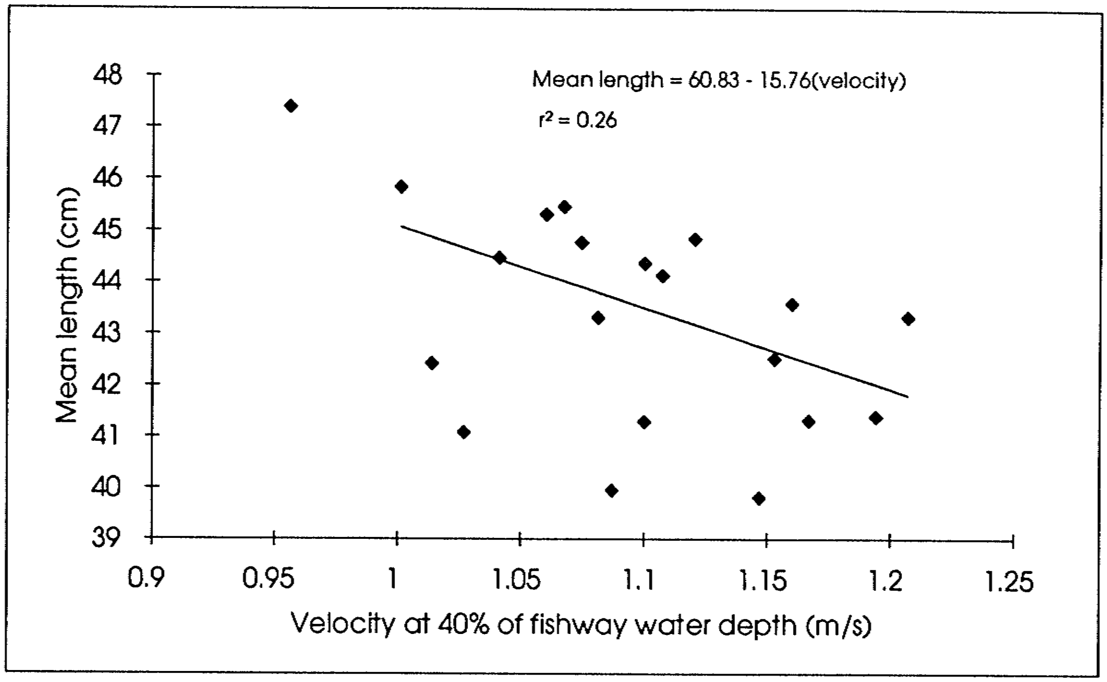


Figure 40. Regression of spent female white sucker mean length and water velocity at 40% of fishway water depth.

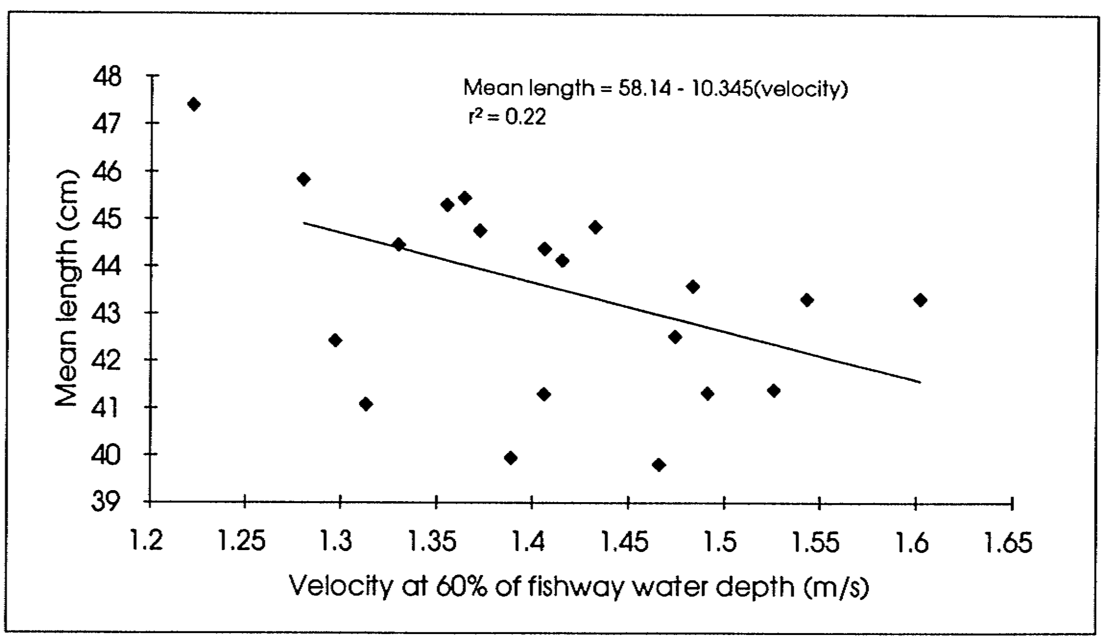


Figure 41. Regression of spent female white sucker mean length and water velocity at 60% of fishway water depth.

TWO-LEVEL DENIL FISHWAY - 1991 & 1992

Air and water temperature

Average daily air and fishway water temperature readings for the 1991 monitoring period are shown in Figure 42. Similar to 1990, water temperatures declined sharply at the end of April due to a period of cold weather. Once warmer weather returned in May, water temperatures increased steadily throughout the remainder of the monitoring period. Water temperatures in the fishway were the same or within 0.5°C of lake surface and tailwater temperatures throughout the 1991 and 1992 monitoring periods.

Fish species

General: A total of 1339 fish of 5 species were captured in 1991 in the fishway exit cage after ascending the two-level Denil fishway. They consisted of 1184 white suckers, 74 northern pike, 45 longnose suckers, 35 walleye, and 1 cisco. An additional 261 fish were observed ascending the upper level of the two-level fishway during visual monitoring. They consisted of 218 white suckers, 21 walleye, 13 northern pike, five longnose suckers and four fish of undetermined species. As in 1990, fish movement through the fishway ceased for a few days during and following a late April blizzard.

A total of 41 fish were observed ascending the fishway during four days of video monitoring in 1992. Thirty-nine fish ascended the upper-level fishway, while only two fish ascended the lower-level one. The number of fish observed using the upper and lower levels of the fishway are significantly different than expected if fish ascended both fishway levels in equal numbers ($P < 0.001$).

Northern pike: Peak northern pike movement through the two-level Denil

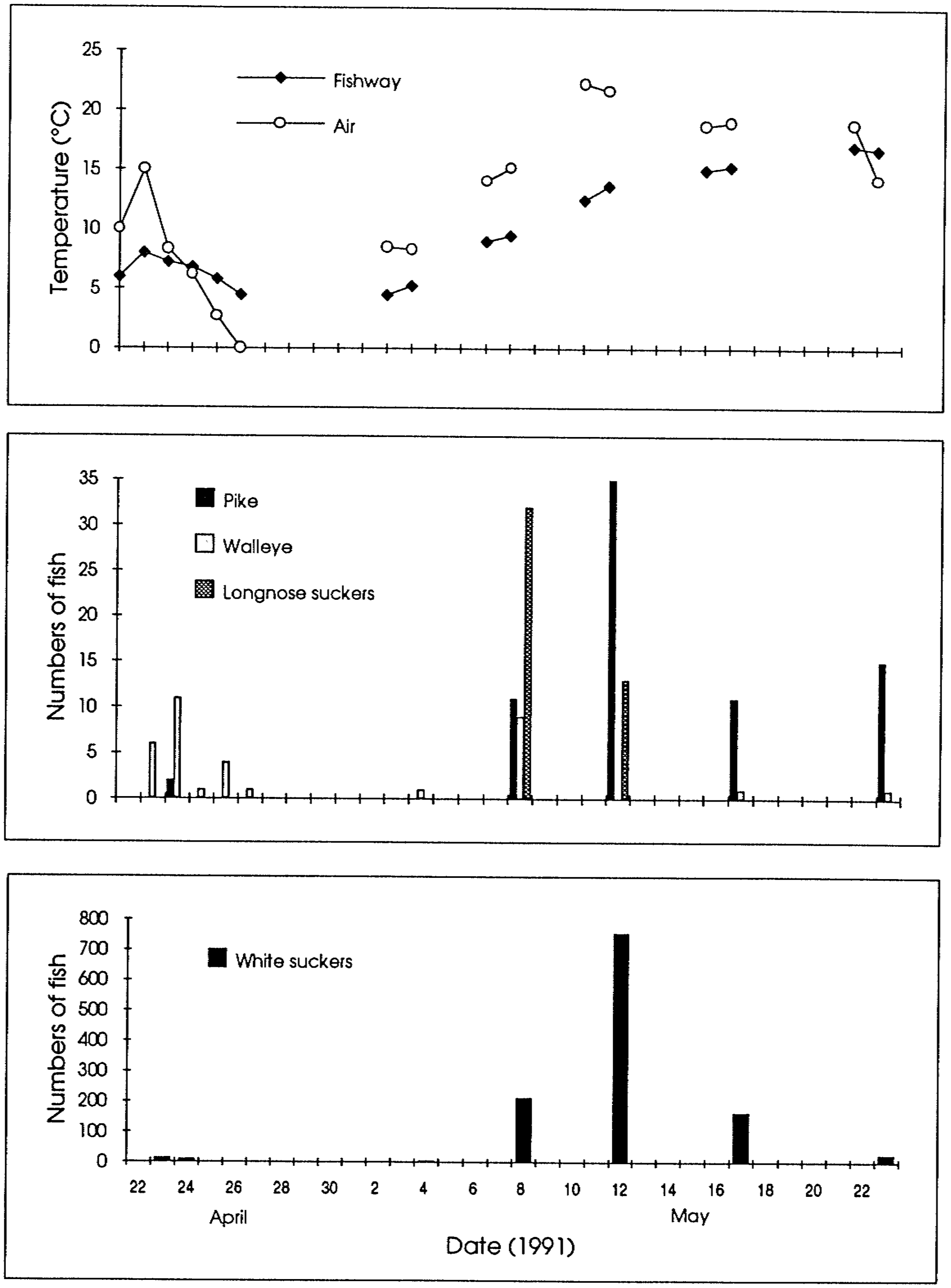


Figure 42. Temporal changes in water temperature and numbers of fish ascending the fishway in 1991.

fishway occurred between May 8 and 23, 1991 (Figure 42). The period of peak movement commenced when the mean daily fishway water temperature reached 9.5°C, and peaked at 13.7°C. Mean length of northern pike captured in the fishway exit cage in 1991 was 52.0 cm, increasing significantly between 1985 and 1990, and between 1990 and 1991 (Table 13).

The mean age of eight northern pike sampled in 1991 was 5.5 years. The age distribution of northern pike sampled in 1991 is shown in Figure 43. The mean age is not significantly different than the mean age of pike sampled in 1990 (t test, $P < 0.05$).

Walleye: Peak walleye movement through the two-level fishway occurred between April 23 and May 11, 1991, and commenced April 23 when mean daily fishway water temperature reached 8.0°C. Due to a period of cooler weather followed by a blizzard, walleye movement declined between April 24 and 27, and finally ceased. Walleye movement began again on May 3, reaching a second peak on May 7 and 8, followed by a decline as the walleye migration ended (Figure 42). The mean length of walleye in 1991 was 41.8 cm. Walleye mean lengths increased between 1985 and 1990, but did not change significantly between 1990 and 1991 (Table 13).

The mean age of 14 walleye sampled in 1991 was 7.7 years. The age distribution for walleye sampled in 1991 is shown in Figure 44. The youngest male walleye in the spawning migration was six years of age. The only female aged in 1991 was five years old and was immature. The mean age of walleye sampled in 1991 is not significantly different than the mean age of walleye sampled in 1990 (t test, $P < 0.05$).

Table 13. Average fork lengths (cm) of fish sampled in the fishway cage in 1985, 1990 and 1991.

	1985*			1990			1991		
Species	Mean length	Standard deviation	Number	Mean length	Standard deviation	Number	Mean length	Standard deviation	Number
Northern pike	42.4[a]	4.02	853	47.0[a,b]	8.75	181	52.0[b]	8.69	72
Walleye	38.7[c]	2.86	341	42.4[c]	4.01	260	41.8	3.87	34
White sucker	40.7[d]	3.15	1229	41.2[d,e]	3.62	2105	41.9[e]	3.32	394
Longnose sucker	42.8[f]	3.94	746	44.6[f,g]	3.91	443	41.8[g]	4.23	45
Cisco	-	-	-	28.5	1.38	113	31.5	-	1
Lake whitefish	-	-	-	36.1	2.03	12	-	-	

* - from Katopodis *et al.* 1991

[a] to [g] - paired t-tests; $P < 0.05$

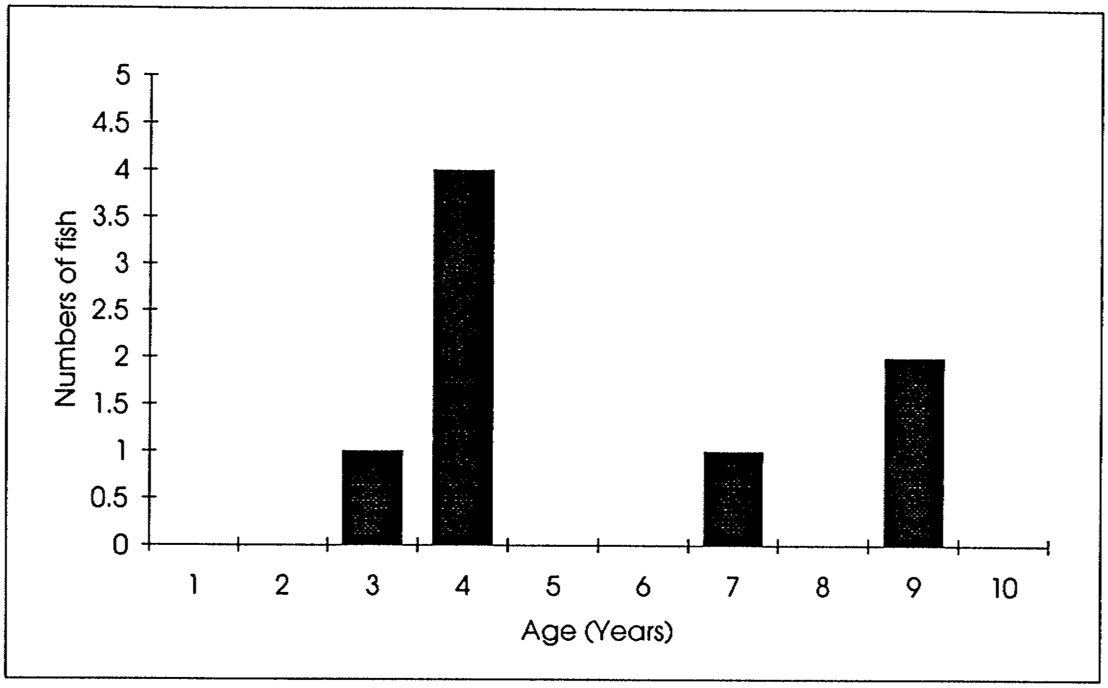


Figure 43. Age composition of northern pike sampled at the fishway cage in 1991.

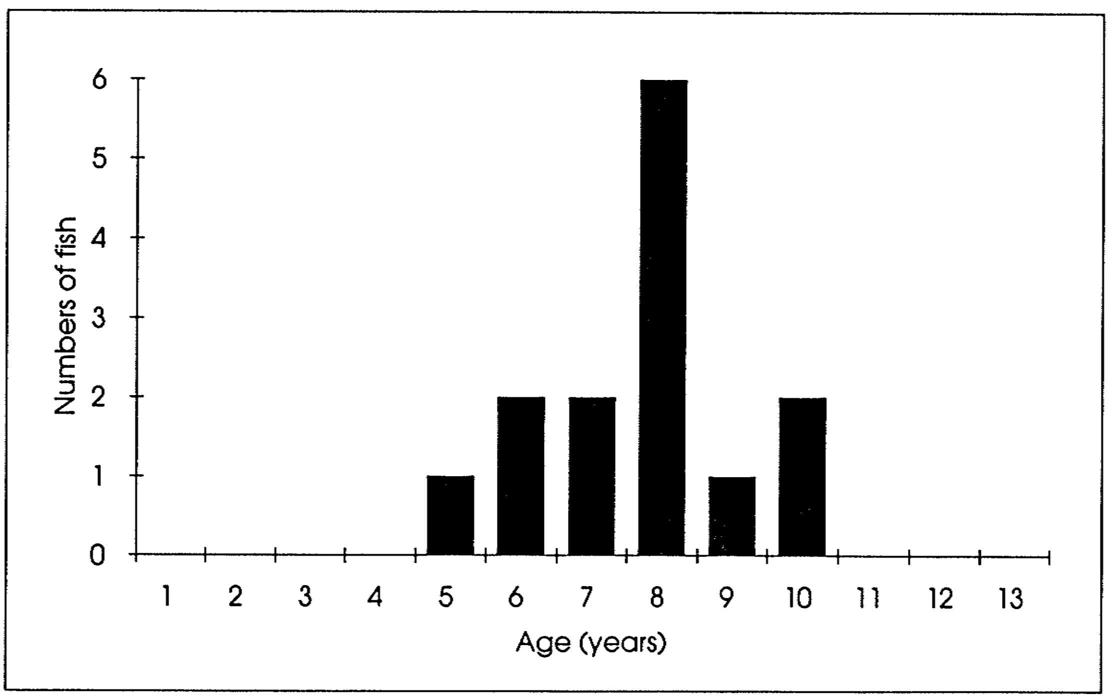


Figure 44. Age composition of walleye sampled at the fishway cage in 1991.

White sucker: Most white sucker movement occurred after the cool weather and blizzard in late April, 1991, with movement commencing on May 7 when the mean daily fishway water temperature reached 9.0°C, and peaked on May 12 when water temperatures reached 13.7°C (Figure 42). White suckers that ascended the fishway in 1991 had a mean length of 41.9 cm. Mean length of white suckers increased significantly between 1985 and 1990, and between 1990 and 1991 (Table 13). White suckers that ascended the fishway in 1991 had a mean age of 7.7 years (Figure 45). Male white suckers in the spawning run had a mean age of 6.9 years; females had a mean age of 8.0 years. Both males and females first entered the spawning run at four years of age.

Longnose sucker: Longnose suckers were first observed ascending the two-level Denil fishway on May 7, 1991. Peak recorded movement occurred May 8, when the mean daily fishway water temperature reached 9.5°C (Figure 42). The mean fork length of longnose suckers that ascended the fishway in 1991 was 41.8 cm. Mean long nose sucker lengths increased between 1985 and 1990, but decreased between 1990 and 1991. Longnose sucker fork lengths in 1985 and 1991 were not significantly different (Table 13). Longnose suckers sampled in 1991 were aged using pectoral finrays. The mean age obtained was 8.5 years; n = 42 (Figure 46). Male longnose suckers in the spawning run had a mean age of 7.5 years; females had a mean age of 9.2 years. Male longnose suckers were found to enter the spawning population at five years of age. Although a few females matured and entered the spawning migration at age five, most appeared to enter when they were about seven years old.

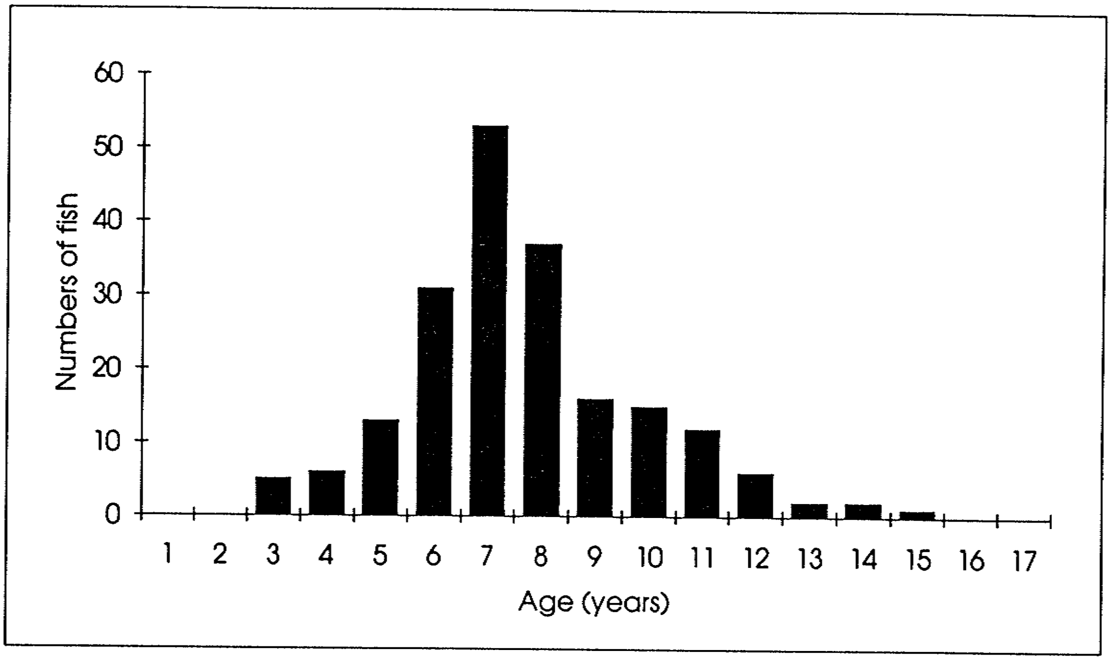


Figure 45. Age composition of white suckers sampled at the fishway cage in 1991.

Figure 46. Age composition of longnose suckers sampled at the fishway cage in 1991.

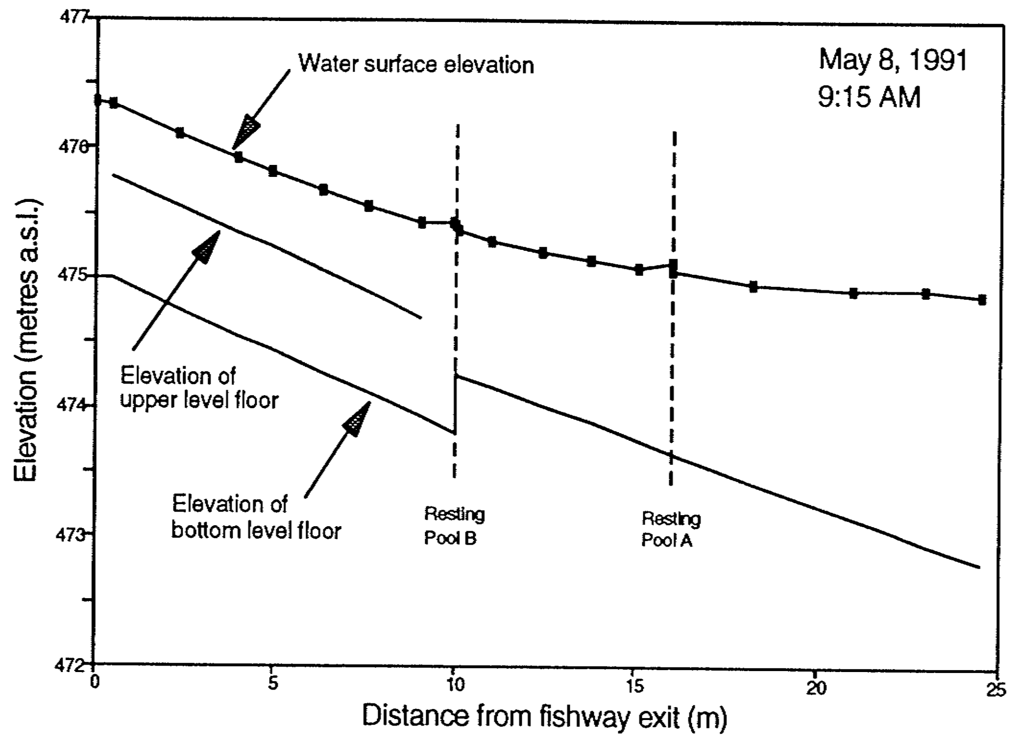
Fishway hydraulic conditions

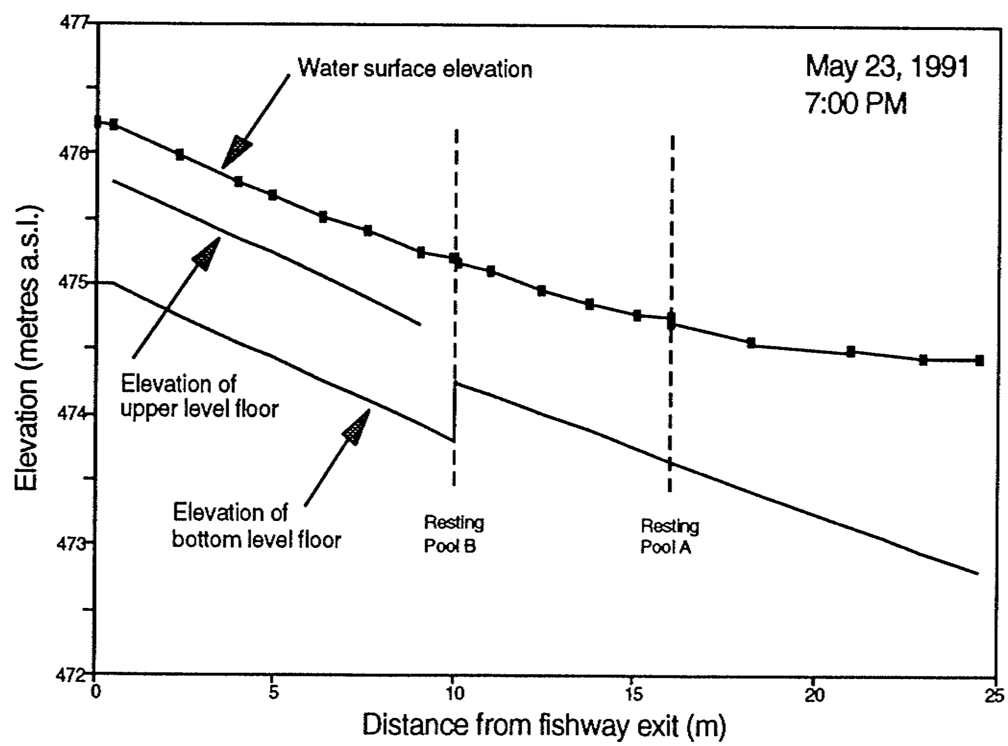
Water surface profiles within the two-level Denil fishway in 1991 are shown in Figures 47 and 48. These profiles represent the highest and lowest water levels recorded in the fishway during the 1991 evaluation period. The greatest water depth at the fishway exit, 1.256 m (corresponding to 0.555 m at the exit of the upper level fishway), occurred on May 8, 1991 at 9:15 AM; the least depth, 1.126 m (corresponding to 0.435 m at the exit of the upper level fishway), occurred on May 23, 1991 at 7:00 PM.

Figure 49 shows fishway water depth and estimated discharge rates at fishway measuring station C in 1991. Water velocities at 60% of water depth at measuring station C in the upper level of the two-level Denil fishway ranged from 0.55 m/s at the start of the monitoring period to 0.38 m/s at the end for 1991. Water velocities at 40% of water depth within the upper level ranged from 0.34 to 0.26 m/s. The estimated water velocities at 60% and 40% of water depth within the lower level remained constant over the monitoring period at 0.51 and 0.32 m/s, respectively, because the lower level of the two-level Denil was totally submerged (Figure 50). By comparison, water velocities at measuring station L (near the upper end of the middle fishway chute) were more than 2½ times the velocities found in the two-level fishway. The middle fishway chute was not modified and retained the configuration of a standard Denil fishway. Water velocities at 60% of water depth at station L ranged from 1.4 m/s to 0.96 m/s over the period of monitoring. At 40% of water depth velocities ranged from 1.1 to 0.75 m/s (Figure 51).

Fish passage and fishway hydraulic conditions

The regression of fish movement and water velocities at station C in the





Figures 47 and 48. Fishway water surface profiles representing the highest and lowest water levels experienced in the two-level fishway in 1991.

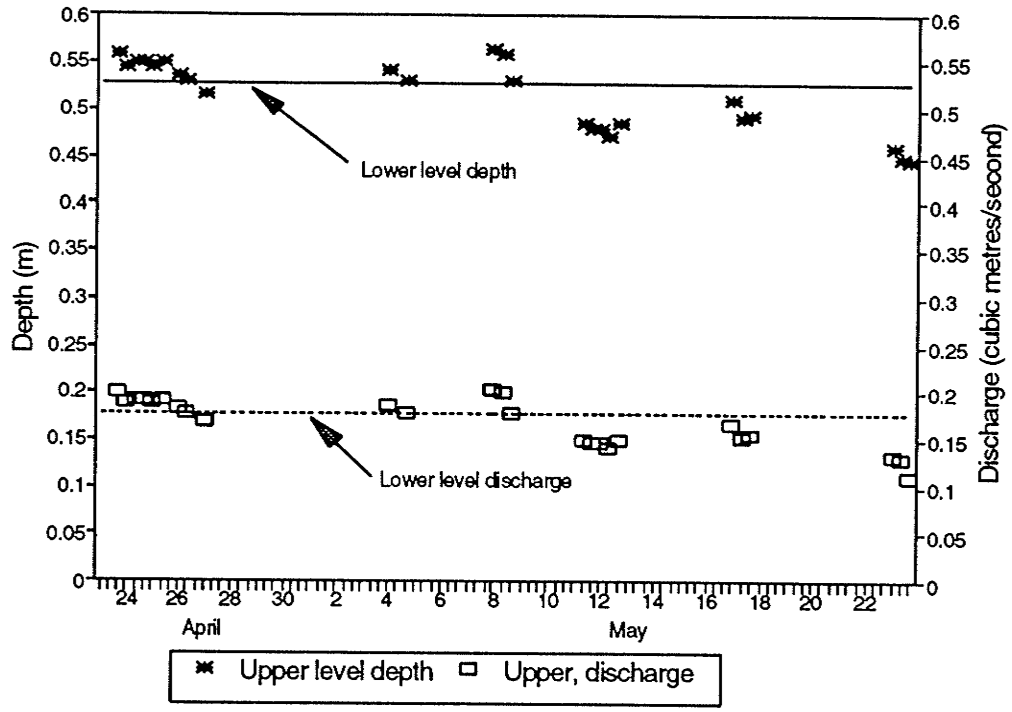


Figure 49. Fishway water depths and estimated discharge rates in the two-level Denil fishway in 1991.

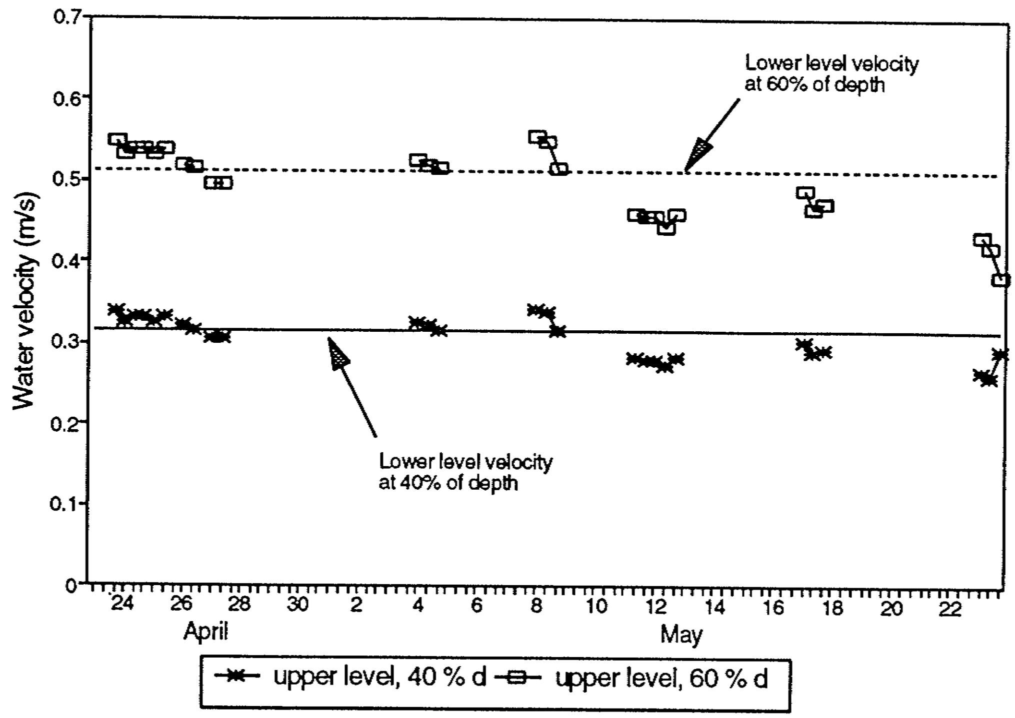


Figure 50. Water velocities at 40 and 60% of water depth in the upper and lower levels of the two-level Denil fishway in 1991.

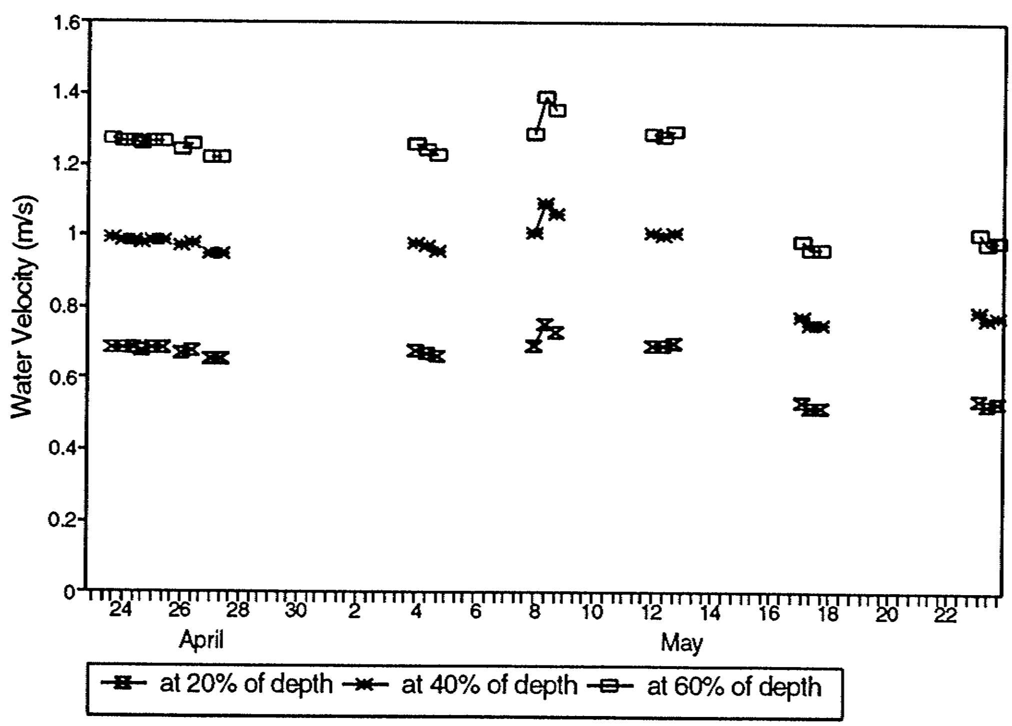


Figure 51. Water velocities at 20, 40 and 60% of water depth in the unmodified middle chute of the standard Denil fishway in 1991.

upper level fishway was done to determine if there was a relationship between the numbers of fish ascending the fishway and estimated water velocities in 1991. The number of northern pike ascending the fishway was found to be negatively correlated with increasing water velocities at both 60% and 40% of the fishway water depth (Figures 52 and 53). As velocities within the fishway increased, the numbers of pike ascending the fishway appeared to decrease. Northern pike movement was not found to be correlated to mean velocity, discharge, or water depth in the upper level of the two-level Denil fishway.

Walleye movement through the fishway was found to be positively correlated to increases in a number of hydraulic parameters within the fishway. As water velocities, water depth and water discharges through the upper level of the two-level Denil fishway increased, so did the number of walleye ascending the fishway (Figures 54 and 55).

White and longnose sucker movements were not found to be significantly correlated with water velocities, depth or discharge within the fishway.

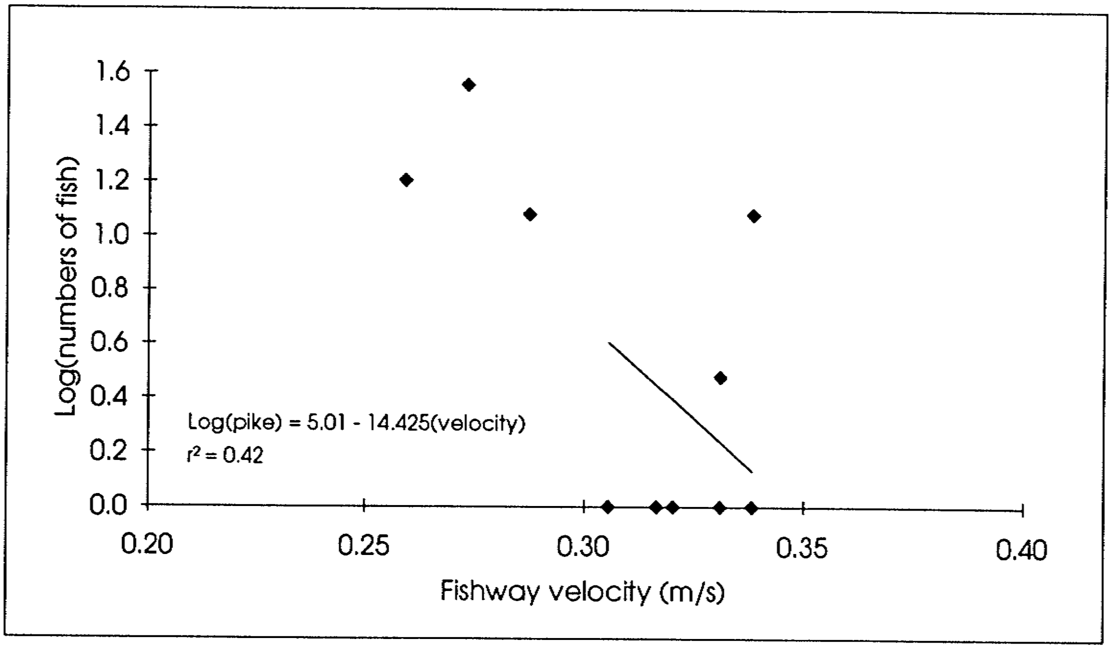


Figure 52. Regression of northern pike movement and water velocity at 40% of fishway water depth in the two-level Denil fishway.

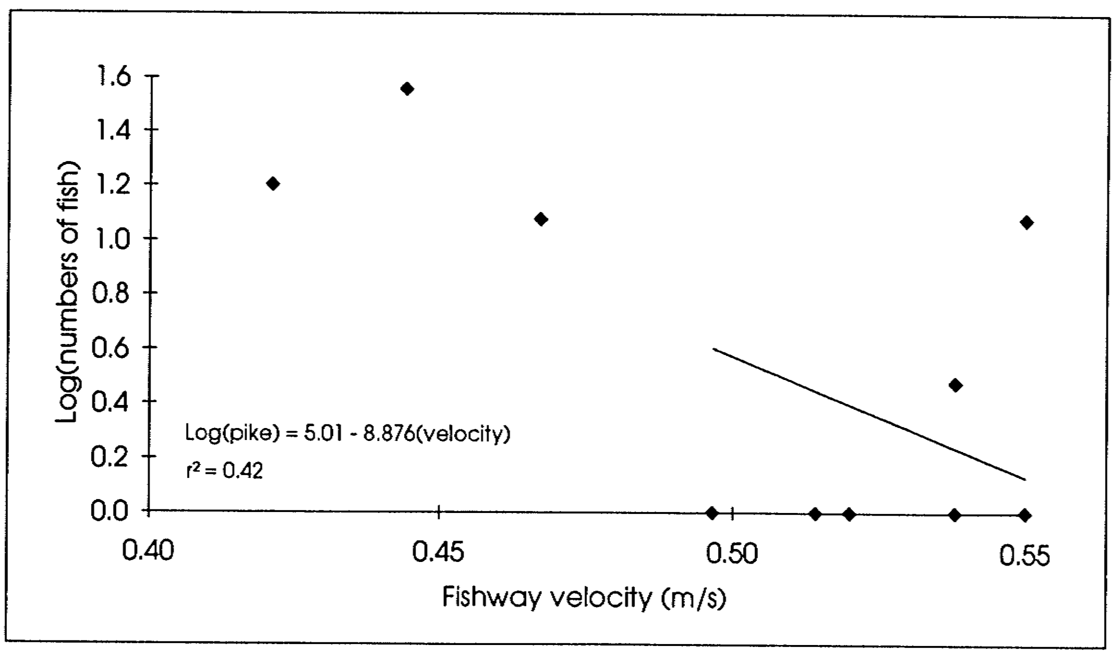


Figure 53. Regression of northern pike movement and water velocity at 60% of fishway water depth in the two-level Denil fishway.

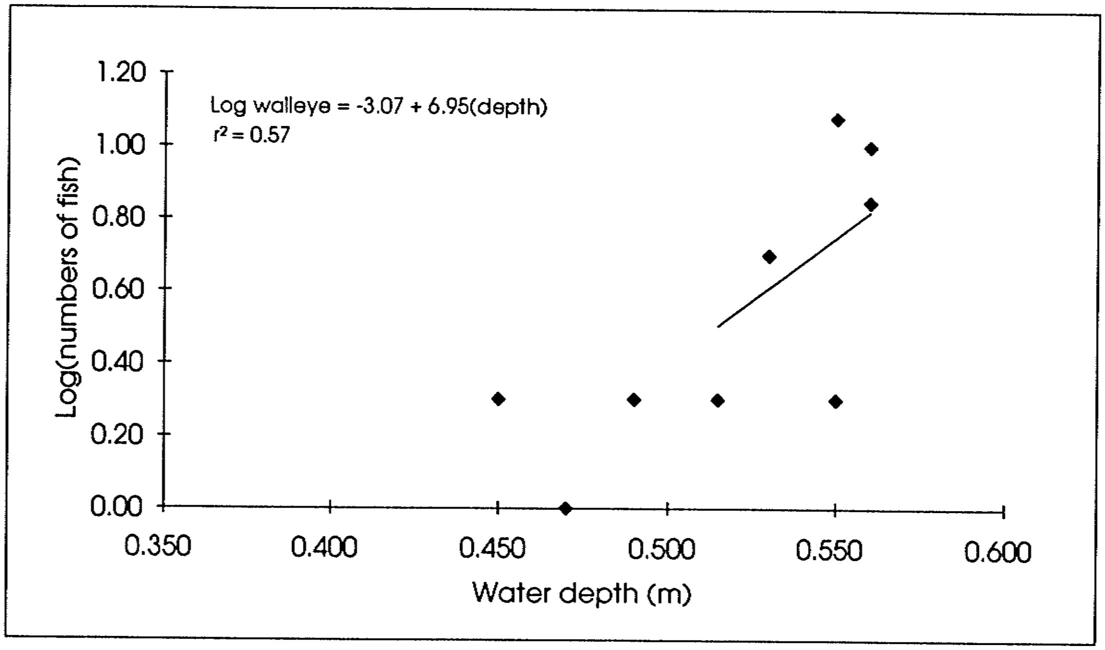


Figure 54. Regression of walleye movement and water depth in the upper level of the two-level Denil fishway.

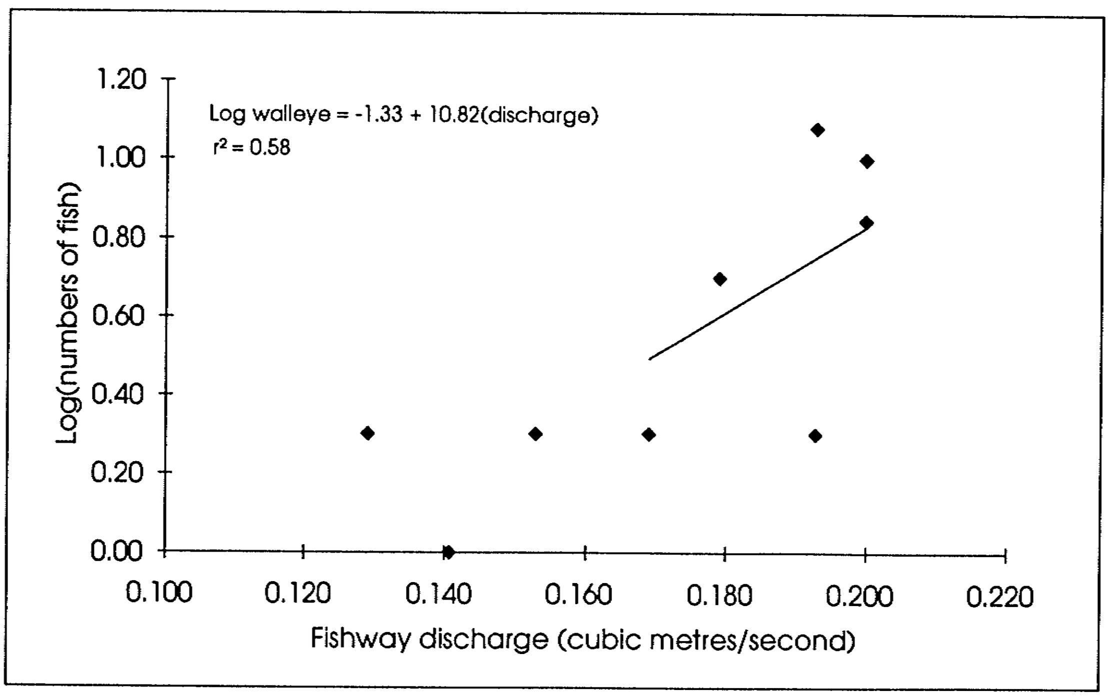


Figure 55. Regression of walleye movement and water discharge through the upper level of the two-level Denil fishway.

DISCUSSION

Fish Species

General: In 1990, migrating fish first appeared at Cowan Dam on April 26, when white suckers ascended the fishway. White suckers and northern pike were also captured at the trapnet located downstream of Cowan Dam that day. As no fish were observed congregating below the dam between April 23 and 25, 1990, it appears likely that fish first arrived in numbers on April 26.

A sharp decline in air temperatures starting on April 26, resulted in water temperatures declining from 9°C to 3°C by April 28, 1990. Visual observation of the tailwater pool, as well as fishway cage returns during and immediately following the cold weather, suggest that most fish left the area below the dam on April 27, 1990 and returned back downriver. Derback (1947) reported that walleye spawning in a tributary of Heming Lake, Manitoba returned to Heming Lake at the onset of colder stream temperatures, and did not return to the stream even after water temperatures increased again. Bodaly (1980), found that walleye, northern pike, white sucker, and longnose sucker spawning in tributary streams of Southern Indian Lake, Manitoba, slowed or stopped their spawning migrations when stream temperatures declined sharply during the spawning run. Once stream temperatures increased again, all species resumed their upstream migration, although sometimes in reduced numbers. Migrating fish were not observed to return in numbers to the tailwater pool below Cowan Dam until May 4, 1990, seven days after the onset of the cold weather. Because high flows made the downstream trapnet ineffective, it is impossible to say whether migrating fish returned in full or reduced numbers. Neither Geen *et al.* (1966), nor Bodaly (1980) found that higher stream discharges had any effect on the timing or number of white and longnose suckers, or walleye in a spawning migration.

More fish used the fishway in 1985 than in 1990. The higher numbers in 1985 may have been due to a larger population of fish being present below the dam than was present in 1990, or because higher tailwater levels in 1985 allowed fish to pass over the dam with less effort. It is impossible to say which of these possible explanations is more likely since no population estimates were made in the earlier study. In 1985, fish were able to pass using only the upper fishway chute. Under 1990 tailwater conditions, all three fishway chutes were required to facilitate fish passage. For one day during the 1990 monitoring period (May 19), the fishway was operated using only the single upper chute as was done in 1985. Only 25 white suckers ascended the fishway that day, compared to 85 the day previous and 771 the day following, when all three chutes were in operation.

The mean lengths of northern pike, walleye, white suckers and longnose suckers that ascended the fishway in 1990 were significantly greater than the mean lengths of fish that ascended the fishway in 1985. This is likely because more favourable passage conditions in 1985 allowed a greater percentage of shorter fish, with less swimming ability, to ascend. High tailwater conditions in 1985 allowed the use of the single upper fishway chute. In 1990, fish had to ascend all three fishway chutes and navigate the turbulent currents in the resting pools to reach Cowan Lake. Fewer fish would have been able to ascend under these conditions.

Resting pool B at the lower end of the upper fishway flume (see Figure 7) was especially turbulent. In all years of the study, fish, usually northern pike, were often observed launching themselves straight up into the air in the fishway pool. They occasionally leapt out of the fishway, or struck the fishway wall or the underside of the steel walkway grating 75 cm above the surface of resting pool B. This behaviour indicates that some species, especially northern pike, had difficulty locating the entrance to the fishway chutes due to turbulent and disorienting currents in the resting pools.

Northern pike and white suckers that ascended the two-level Denil in 1991 were significantly longer than northern pike and white suckers that ascended the standard Denil fishway in 1990. The mean length of longnose suckers decreased between 1990 and 1991, while walleye mean lengths did not change. With the reduced velocities in the two-level Denil, the mean lengths of all species would be expected to decrease since lower fishway velocities should have allowed smaller fish to ascend successfully. Instead, mean northern pike and white sucker lengths increased. This may be due to sampling errors from the shorter monitoring period in 1991. A limited monitoring period could have missed changes in northern pike and female white sucker mean lengths over time as was documented in 1990. The decline in longnose sucker mean length between 1990 and 1991 can be attributed to easier passage of shorter longnose suckers due to reduced water velocities in the two-level Denil.

The increase in mean northern pike length can not be attributed to natural variation in age class composition caused by reduced recruitment of younger, shorter fish into the spawning population or reduced mortality of older, longer fish. The age composition of northern pike sampled in 1991 was not significantly different from the age composition of pike that ascended the fishway in 1990. The mean age of walleyes sampled in 1990 and 1991 was not significantly different either. The age compositions of white and longnose suckers in 1990 and 1991 could not be compared as age samples were only obtained in 1991.

The fishway trap was not totally effective in enumerating fish passage through the fishway. Observations showed that although most fish were retained by the fishway trap once they had ascended the fishway and entered it, some fish returned back down the fishway. The fishway cage entrance was visually monitored on a number of occasions on May 22 and 23, 1990. From this monitoring it appeared that increasing numbers of fish left the fishway cage and returned back down the fishway as the cage became more crowded. Monitoring indicated that use of the fishway exit cage for capturing fish after they ascended the fishway under-estimated total fish passage by as much as 10% when numbers in the cage were low, to almost 100% when numbers in the cage were high.

Freshly injured fish were occasionally captured in the fishway cage. Injuries observed ranged from minor to severe body lacerations, broken or missing gill covers or fins, and smashed eyeballs. As the cage became crowded and fish returned back down the fishway, some were likely swept back onto the sharp edges of the steel fishway baffles by the swift flows. In order to be recaptured at the fishway cage, these injured fish had to have re-ascended the fishway.

Fish that ascended the Cowan River during the spring spawning migration appeared to originate in Lac Ile-a-la-Crosse, and possibly the lower Beaver River. This is substantiated by tag returns, and by the fact that both the Cowan River and the Beaver River above its junction with the Waterhen River become anoxic and unsuitable for fish life during the winter (Saskatchewan Environment and Resource Management, Fisheries Branch files). If spawning fish originate in Lac Ile-a-la-Crosse, they must migrate at least 185 km to reach Cowan Dam.

No significant relationship was found between the movement of walleye, longnose suckers, cisco or whitefish, and hydraulic conditions within the standard Denil fishway in 1990. Walleye and longnose suckers appeared to be able to ascend the Denil fishway at Cowan Dam without difficulty or major delay. No fish species appeared to have any difficulty in locating the fishway entrance either, in spite of high control gate releases during portions of the evaluation period.

Northern pike: Based on the spawning condition of northern pike that ascended the fishway, most pike spawned below the dam and did not continue migrating upstream. The Cowan River below Cowan Dam has a fairly small channel and a wide grassy flood plain which is totally inundated when average or greater flows are released from Cowan Dam. As a result, many hectares of suitable pike spawning habitat exist downstream of the dam.

Most of the pike that ascended the fishway did so in late May and early June, well after spawning had been completed. This pattern of movement was also observed during the 1985 study when the fishway was operated as a single chute (Katopodis *et al.* 1991). Schwalme *et al.* (1985) also documented considerable use of fishways on the Lesser Slave River in north-central Alberta by post-spawning pike. Northern pike movement through the fishway was strongest during the day in 1990. In 1985 the rate of passage was found to be greatest in the late afternoon and early evening. The lowest rate of pike passage occurred at night. This pattern of upstream migration is typical of that reported in the literature.

Fernet (1984) and Katopodis *et al.* (1991) speculated that northern pike may congregate in the tailwater area below fishways because they are good feeding areas. However, the large numbers of northern pike that congregated below Cowan Dam did not appear to do so in order to forage. Eighty-four percent of pike lethally sampled at the fishway cage in 1990 had empty stomachs. A 13 year study of the feeding habits of pike at Heming Lake, Manitoba found only 45% of pike on average to have empty stomachs. The highest average percentage of empty stomachs reported for any year was 58% (Lawler 1965). It is unlikely that pike were actively feeding as only three pike contained food, i.e., amphipods. Furthermore, there were enormous numbers of amphipods in the tailwater pool, presumably having been carried by flows from Cowan Lake. No forage fish species were observed in the tailwater pool during the monitoring period.

In both 1985 and 1990, northern pike took substantially longer on average to ascend the fishway after being tagged than did white suckers (Table 14). This was found to be true at the Fawcett Lake Denil fishway in 1983 as well.

Table 14. Delay times between tagging and fishway ascent for northern pike and white suckers.

Fishway	Year	Delay time (days)	
		Northern pike	White suckers
Cowan Dam	1985[a]	16.2	7.7
Cowan Dam	1990	11.0	5.2
Fawcett Lake	1983[b]	9.9	2.2

a - from Katopodis *et al.* 1991
b - from Fernet 1984

Northern pike that ascended the fishway were shorter than pike sampled at the downstream trap and in the tailwater pool. This difference in sizes between ascending and non-ascending pike has been documented in other fishway studies as well. Fernet (1984) and Halstead (1984) found that pike ascending the Fawcett Lake Denil fishway were shorter than fish sampled at the downstream counting fence. Schwalme and MacKay (1985) documented that pike that ascended Denil and vertical slot fishways at Lesser Slave Lake were shorter than those seined below the fishways. More recently, Orr (1993) found a size differential between pike that ascended Denil and steeppass fishways at Siisiip Marsh, and pike sampled from the river channel below the fishways.

The observed size difference between pike captured below the dam and pike that climbed the fishway is not likely due to differences in swimming ability. Numerous authors have reported that larger fish are stronger swimmers than smaller fish, and can swim against higher velocity flows (Jones *et al.* 1974; Beamish 1978; Pavlov 1989). It is therefore unlikely that the observed size difference is due to swimming ability. Schwalme and MacKay (1985) suggest that smaller pike may be more motivated than larger pike to migrate upstream. Orr (1993) speculated that smaller pike may exhibit a stronger reaction to high water flows than larger pike. From occasional observations of pike attempting to ascend the Cowan Dam Denil fishway, it appeared that smaller fish were more likely to attempt to ascend the fishway than larger pike observed swimming idly in the tailwater pool.

The mean length of northern pike ascending the fishway declined over the period of peak pike movement. No reference could be found in other studies to similar temporal declines in pike length. There is a possibility that the larger, female pike returned downriver earlier than the smaller male pike, although there is no evidence to support it.

According to reported recaptures of tagged fish, anglers harvested almost

20% of the northern pike that congregated below Cowan Dam in the spring of 1990. This should be considered a minimum harvest level since not all tagged pike recaptures were necessarily reported. The harvest level of tagged pike released into Cowan Lake was only 3% in 1990, and less than 2% in 1991. These lower harvest levels are likely because the fish were able to disperse over a much larger area in the lake, and because of reduced angler effort on Cowan Lake relative to the tailwater pool. On the Victoria Day weekend in May, 1990, a total of 43 camping units were set up in the small campground at Cowan Dam, primarily to angle for pike in the tailwater pool. The Victoria Day weekend marked the start of the angling season downstream of Cowan Dam, although the season opened two weeks earlier above the dam in Cowan Lake. On one occasion on the opening weekend of the 1990 angling season, 30 people were observed angling for pike at one time in the less than 0.5 hectare tailwater pool. For the duration of the week following, between 10 and 15 people were observed angling in the tailwater pool at any given time during the day.

Although most tagged pike were recaptured within one km of the tagging site due to the intensive angling effort in that area, four pike were caught by anglers many miles downstream of Cowan Dam. From the distribution of the four downstream recapture sites, it appears that pike that spawn below Cowan Dam in the spring disperse widely throughout the Beaver River and connecting lake and river systems after spawning is completed.

Only one of 40 pike tagged at the downstream trap was recaptured after ascending the fishway, perhaps due to most tagging at the downstream trap occurring before the severe spring blizzard that halted spawning migrations. Pike that spawned before the blizzard may not have returned to the area once water temperatures increased again.

The estimated passage rates for pike (12.1%) at Cowan Dam fishway are similar to estimated passage rates for pike (10.4%) determined for the Fawcett Lake Denil fishway (Fernet 1984), and exceed passage rates for the Fawcett Lake Denil fishway before improvements were made. Only Orr (1993) documented higher pike passage rates through a standard Denil fishway than Cowan Dam. Pike passage rates at the Siisiip standard Denil fishway ranged from 4% to 18%, while passage rates ranged from 9% to 32% through an adjacent, concurrently operated steeppass fishway. Steeppass fishways are a variation of the Denil fishway with a different baffle configuration which results in significantly different flow patterns and velocity profiles within the fishway (Katopodis and Rajaratnam 1983). Water velocities in a standard Denil fishway are lowest near the floor of the fishway, increasing towards the surface. In a properly designed steeppass fishway, water velocities are highest near the floor of the fishway and decrease towards the surface (Rajaratnam and Katopodis 1991).

Northern pike, and white and longnose suckers were occasionally observed attempting to ascend the final chute of the fishway near the water surface. This is similar to observations made at the fishway in 1985 (Katopodis *et al.* 1991). In all cases, the fish were unable to swim more than two or three metres before being swept back down into resting pool B. As can be seen in Figure 36, water velocities at 60% of the water depth in the fishway are often more than twice the velocities found at 20% of the depth. Velocities at the fishway water surface are even higher. As previously suggested by Katopodis *et al.* (1991), if pike prefer to swim near the surface they would face much higher velocities than species that may ascend at lower depths within the fishway. Indirect evidence collected during the 1990 study also suggests that pike attempted to ascend near the surface of the fishway. In 1990, northern pike movement was significantly related to water velocities at 60% of water depth within the fishway ($r^2 = 0.27$; $P < 0.05$), but was not related to water velocities at 40% or 20% of water depth. Since only the estimated water velocities closest to the surface were significantly related to pike movement, it is probable that most pike attempted to ascend the fishway near the surface. Pike movement was also found to be significantly correlated with water velocities at both 40% and 60% of water depth in the upper level of the two-level fishway in 1991 ($r^2 = 0.42$; $P < 0.05$). Although these correlations were statistically significant, the low r^2 values indicate that only a relatively small amount of the variability in pike movement in both 1990 and 1991 can be accounted for by changes in fishway water velocity. Other unknown factors appear to have a greater influence on pike movement through the fishway than does water velocity.

Pike may have been more successful in ascending against the reduced velocities in the two-level Denil, than against the higher velocities found in the standard Denil. Based on the number of pike that ascended the standard Denil fishway during 39 days of monitoring in 1990 (n=181), and the number that ascended the two-level Denil in 10 days of monitoring in 1991 (74), significantly more pike would have ascended the two-level Denil than ascended the standard Denil (G test; $P<0.005$).

In 1990, the mean length of northern pike ascending the fishway decreased as water velocities at 40% and 60% of fishway water depth decreased. This corresponds to the findings of Jones *et al.* (1974) that larger fish are able to swim against higher velocities than smaller fish. As water velocities in the fishway declined, smaller pike were able to ascend. Northern pike movement was not found to be related to attraction flows, nor to differences in total hydraulic head. It appears that pike movements through the standard Denil fishway in 1990 and the two-level Denil in 1991 were at least partially constrained by water velocities within the fishways. Although pike behavior may also have an effect on pike movement, high water velocities clearly have a negative impact on fishway ascent.

Walleye: Based on 1990 data, it appears that walleye ascended the fishway in order to complete their upstream spawning migration. Considering the normal distribution of walleye movement through the fishway, the pre-spawning condition of the fish, the short time required for the spawning migration to pass, and the lengthy period following peak movement when no other walleye ascended the fishway, it does not appear that walleye experienced any serious difficulty in passage. A few walleye were observed in the tailwater pool about the time that peak movement through the fishway occurred, but they disappeared from the pool about the time that walleye movement through the fishway ceased. A brief cold period coinciding with the end of peak walleye movement may have caused any walleye remaining in the tailwater pool to return downriver.

Although walleye are reported to most actively migrate at night, diurnal walleye movement at the Cowan Dam fishway peaked during the late afternoon (1500 to 1900 hours). Light conditions are likely sufficiently low within the lower depths of the fishway that walleye will use it during the day. The late afternoon migration peak may also be related to peak daily water temperatures. Increasing water temperatures have been documented to induce upstream walleye movement by Rawson (1957) and Bodaly (1980).

The walleye length distribution followed a normal curve indicating that the fishway did not select against smaller fish. This is supported by a comparison of mean lengths of walleye sampled at the downstream trap and at the fishway cage. There was no significant difference in fork lengths between walleye sampled at these locations.

Only one of seven walleyes examined for feeding habits had anything in its stomach. This suggests that walleye were not congregating in the pool for foraging purposes, but were there as part of a spawning migration.

Although walleye scales were collected, they were not aged due to difficulties in identifying locations of annuli. Campbell and Babaluk (1979), recommend that scales not be used for aging walleye over eight years of age, due to their lack of reliability compared with sections made from bony structures such as opercles, dorsal fin spines, otoliths and vertebrae. Walleye mean age obtained from otoliths was 7.6 years in 1990 and 7.7 years in 1991. Ages obtained from otoliths appear to be reliable because the strongest age class in 1990 (seven years old) was also the strongest age class in 1991 (eight years old). Male walleye mature and enter the spawning run as young as six years of age. The youngest mature female was seven years old. These ages are older than those reported by Bodaly (1980) for walleye spawning in tributary streams of Southern Indian Lake, Manitoba, and by Rawson (1957) for spawning runs at Lac La Ronge, Saskatchewan. At both of these locations mature males and females first entered the spawning runs at five years of age.

In 1990, walleye appeared to be able to ascend the standard Denil fishway without obvious difficulty or delay. No significant relationship was found between walleye passage and hydraulic conditions within the standard Denil fishway. However, walleye passage in 1991 appeared to be negatively affected by the two-level Denil design. Although the period of walleye movement in 1991 lasted almost three weeks instead of four days as in 1990, the number of walleye that successfully ascended the fishway appears to have been reduced. This suggests that the two-level Denil caused passage problems for walleye. Walleye passage increased as water velocities, discharge and depth in the two-level fishway increased. This suggests that walleye did not like the reduced flows in the two-level fishway. As water velocity, discharge and depth increased, flow conditions within the fishway appeared to become more suitable for walleye passage.

Although none of the 110 walleye tagged at Cowan Dam in 1990 and 1991 were captured by anglers in the immediate vicinity of the dam, over 16% (18) of tagged walleye were eventually harvested by anglers or commercial fishermen. This is a much higher rate of harvest than was previously thought for the Beaver River system, especially considering the dispersed nature of the recapture sites. It is likely that the harvest rate was even higher than 16% for the following reasons: no reward was offered for the return of tags; no advertising was done requesting people to report tagged fish to the conservation officers; and, commercial fishermen are often reluctant to return tags from their catch in case the Government decides to reduce the commercial fishing quota for the lake. A number of the commercially caught tagged fish were reported by the fish plant operator in Buffalo Narrows, not by the fishermen themselves.

From the wide distribution of the recapture sites, it is apparent that the walleye which ascend the Cowan River to spawn are part of a much larger population that inhabits Lac Ile-a-la-Crosse and the Beaver River system. Most walleye that ascended the fishway into Cowan Lake did not remain there but returned downriver. Only one of the 18 tagged walleye recaptured by anglers or commercial fishermen was caught in Cowan Lake. Although 15 of the tagged walleye recaptures were released into Cowan Lake after tagging, they left the lake and returned down the Cowan River within one month of entering the lake. By June 5, 1990, both the fishway and dam release gates were closed for the summer due to low lake levels. Because the Cowan and upper Beaver River systems become anoxic in the winter, it is likely that most fish winter in Lac Ile-a-la-Crosse and/or the lower Beaver River. This is at least partially corroborated by two November walleye recaptures and a February pike recapture from Lac Ile-a-la-Crosse.

White sucker: During the 1990 monitoring period 29% of white suckers ascended the fishway prior to spawning, while the remaining 71% ascended after spawning or were immature. Obviously, most white suckers found suitable spawning habitat below the dam, although none were observed in the act of spawning. While some did ascend the fishway in order to complete their spawning migration, most did not.

Daily white sucker movement through the fishway peaked during the late afternoon (lift 3, 1530 to 1900 hours), the time of day when daily water temperatures peaked. This was also the time of day when the white sucker passage rate was highest at Fairford fishway in 1987, and at Cowan fishway in 1985 (Katopodis *et al.* 1991).

The fishway does not appear to select against white sucker passage on the basis of length. Although there was a significant difference in mean lengths between white suckers sampled at the downstream trap and in the tailwater pool, there was no difference in mean lengths between white suckers from either sampling location below the dam and those sampled at the fishway exit cage. The difference in mean lengths between the downstream trap and tailwater pool could be a function of the date when fish from each location were tagged. Most fish at the downstream trap were tagged prior to the cold snap that caused them to return downriver. Fish tagged in the tailwater pool were tagged after they had returned upriver.

Although male white suckers maintained a uniform mean length over the duration of the monitoring period, female white suckers did not. The size of both pre-spawning and spent females that passed through the fishway declined as the season progressed. Fernet (1984) reported a significant decrease in mean length of white suckers between the early and latter part of the Fawcett Lake Denil fishway study. He did not differentiate between male and female lengths however. He attributed the difference to the smaller white suckers escaping the upstream trap through holes in the counting fence during the early part of the study, or to movement of larger individuals early in the spawning run, followed by movements of smaller, immature individuals. At Cowan Dam the small size mesh of the fishway cage prevented small individuals from escaping. It is more likely that larger females run earlier in the spawning migration than smaller, though still mature, females. In the Cowan Dam study, immature individuals were excluded from the length versus time analysis. The above findings are corroborated by a comparison of the mean lengths of pre- and post-spawning males and females. Although pre- and post-spawn males, and pre-spawn females had equivalent lengths, post-spawning females were significantly longer. This can be explained if larger female white suckers spawn earlier than the smaller females. By the results of the daily mean length versus time analysis, larger females also appear to migrate earlier than do smaller ones.

The fishway did not appear to select for white sucker passage on the basis of sex. The sex ratio of white suckers tagged at both the downstream trap and the tailwater pool were compared with the sex ratios of tagged white suckers from each location that ascended the fishway. In neither case were the ratios significantly different.

A higher percentage of white suckers tagged in the tailwater pool ascended the fishway than did white suckers tagged at the downstream trap. This is likely due to many of the downstream trap fish being tagged before the spring blizzard. The resultant sharp decline in water temperature appears to have caused most fish to return downriver until water temperatures increased again. It appears likely that many of the fish that migrated into the area initially, did not return once temperatures increased again. While the recapture of fish tagged on April 26 or 27, 1990 confirms that some white suckers returned to the area of the dam once water temperatures warmed again, the reduced recapture rate for fish tagged prior to the blizzard suggests that many of them did not.

The estimated passage rates for white sucker (58.8%) at Cowan Dam fishway are similar to estimated passage rates for white suckers (58.5%) determined for the Fawcett Lake Denil fishway (Fernet 1984). This is the highest documented passage rate of any freshwater fish reported in studies of prairie fishways.

The mean length of spent female white suckers was found to decrease as water velocities increased. This is opposite to what was expected. As the length of a fish increases, so does its swimming ability (Jones *et al.* 1974). Although the correlation of spent female white sucker mean length with fishway water velocities at 40% and 60% of water depth was statistically significant, the low r^2 values (r^2=0.26 & r^2=0.22) indicate that changes in water velocity account for only a minor amount of the variability in spent female white sucker mean length. The progression of time over the course of the monitoring period accounted for most of the variation in mean length (r^2=0.85).

In 1990, white sucker movement was not found to be related to attraction flows, nor to differences in total hydraulic head. They appeared to be able to ascend the fishway without major difficulty. The three days of peak movement in 1990 did not coincide with any major change in fishway water velocities or other hydraulic event. In 1991, white sucker movement through the two-level Denil fishway was not found to be related to hydraulic conditions within the fishway either. By virtue of the fact that 775 white suckers were captured in the fishway trap on May 12, 1991, it is evident that the two-level Denil fishway did not negatively impact white sucker movement.

Tagged white sucker recaptures reported from the commercial fishery at Lac Ile-a-la-Crosse indicate that fish that spawn at Cowan Dam likely originate from Lac Ile-a-la-Crosse. No white sucker tag returns were reported from other commercially or domestically netted lakes in the area. The age composition, sex ratio and mean length of white suckers sampled at the Cowan fishway are very similar to those reported by Durbin and Fernet (1979) for white sucker populations spawning in other streams flowing into Lac Ile-a-la-Crosse.

Longnose sucker: Longnose sucker movement through the Cowan Dam Denil fishway in 1990 appeared to be part of their spring spawning migration. Almost 98% of the longnose suckers that ascended the fishway did so prior to spawning. Peak movement generally occurred at cooler temperatures than were reported in the literature. In 1985, 1990, and 1991, temperatures at time of peak longnose sucker movement at the Cowan Dam fishway were 11°C, 8°C and 9.5° C, respectively. Peak movement occurred at 14°C at Yellowstone Lake (Brown and Graham 1954), at about 13°C at Sixteenmile Lake (Geen *et al.* 1966), and between 11°C and 14.5°C in Western Lake Superior (Bailey 1969). Peak longnose sucker movement through the fishway occurred between mid-afternoon and early evening. This is approximately the same period of peak diel movement as was observed by Geen *et al.* (1966).

Some longnose spawning activity was observed below the dam in 1991. The spawning act took place during daylight hours near the outlet of the tailwater pool over a clean gravel substrate. The water was 20 to 40 cm deep and had a moderately swift current. Longnose suckers at Sixteenmile Lake, British Columbia spawned under very similar conditions (Geen *et al.* 1966).

Although longnose suckers that ascended the fishway were longer than those sampled below the dam, the significance of the t-test is questionable since the sample from below the dam consisted of only five fish. The normal curve of the length frequency distribution does not suggest that the fishway was selecting for passage of larger longnose suckers.

Male longnose suckers were significantly shorter than females. Although the difference did not prove to be statistically significant, males in the spawning migration were younger on average than females. These differences in length and age between sexes have been documented by other authors. Both male and female longnose suckers first entered the spawning migration at five years of age. This is roughly the age of first spawning found at Sixteenmile Lake, British Columbia by Geen *et al.* (1966).

Longnose sucker appear to be able to ascend the standard Denil fishway at Cowan Dam without any obvious difficulty or major delay. No significant relationship was found between longnose sucker passage and hydraulic conditions within the standard Denil fishway in 1990. The modification of the fishway to a two-level design did not appear to affect longnose sucker movement either. In 1991, movement occurred over about a one week period, the same as in 1990. No relationship was found between longnose sucker movement and hydraulic conditions in the two-level fishway.

In spite of many thousands of longnose suckers having ascended the fishway since it opened in 1985, fish population assessments carried out by Saskatchewan Environment and Resource Management, Fisheries Branch have not caught any longnose suckers in Cowan Lake. This fits with observations made by Geen *et al.* (1966) that longnose suckers do not remain on the spawning grounds, but return downstream soon after spawning is completed.

Cisco, lake whitefish and yellow perch: The cisco and lake whitefish that ascended the fishway appear to have reached Cowan Dam about a month later than the other species. The first schools of whitefish and cisco were observed in the tailwater pool on May 26, 1990. Cisco and whitefish have been associated with spring spawning migrations at other locations. Schwalme *et al.* (1985), and Katopodis *et al.* (1991), reported cisco and lake whitefish movement through fishways, in Alberta and Manitoba respectively, during the spring. Tomich *et al.* (1982) reported large numbers of Rocky mountain whitefish, another fall spawning species, using the Carsland Dam on the Bow River in Calgary during late July. No attempt was made by these authors to explain this behavior. Perhaps cisco and whitefish followed the four spring spawning species into the area to feed on freshly spawned fish eggs and newly hatched fish fry. Both cisco and whitefish have been reported to eat the eggs and fry of other fish species (Bidgood 1973; Scott and Crossman 1973). This cannot be shown with certainty as neither cisco nor whitefish stomach contents were examined.

Daily cisco movement through the fishway followed the same pattern as did walleye, and white and longnose suckers. The period of peak movement was between 1530 and 1900 hours, with the next highest rate of movement being between 0930 and 1500 hours. The lowest rate of passage occurred at night. Whitefish did not show any discernible preference regarding time of day to ascend the fishway.

It is possible that cisco and whitefish ascended the fishway in order to reach the cooler water of the lake. By May 26, 1990, when schools of cisco and whitefish were first observed in the tailwater pool, average daily water temperatures had reached 18°C. This is only 2°C less than the upper lethal temperature of 20°C reported by Colby and Brooke (1969). By May 28, the average daily water temperature had reached 19.8°C. Peak cisco movement did not occur until after a period of cooler weather had reduced the average daily water temperature to 16.7°C. Even at this temperature cisco could withstand very little handling. Immediate handling mortality did not occur if fork length measurements only were obtained before they were released into Cowan Lake. Any attempt to tag or even weigh cisco or whitefish resulted in their immediate deaths.

Cisco and whitefish ages obtained from scales and otoliths corresponded fairly well. In some of the older fish however, otoliths often gave ages that were one or two years older than those obtained from scales. All cisco and whitefish sampled were mature.

Neither cisco nor whitefish movement through the fishway were found to be influenced by fishway velocities, attraction flows or total hydraulic head.

Yellow perch do not appear to have ascended the fishway in any of the years it was studied. Although yellow perch in spawning condition were captured below Cowan Dam, it is impossible to say whether they reached Cowan

Dam as part of a spawning migration, or whether they were swept downstream out of Cowan Lake. In 1992, a number of yellow perch were captured ascending the Cowan River at a walleye spawn camp trapnet near the Cowan River's junction with the Beaver River. However, Cowan Lake also supports a large perch population; they could have been carried out of the lake with discharge through the dam release gates.

Fishways

One of the primary reasons for installing a Denil fishway at Cowan Dam was to facilitate the movement of spawning pike into Cowan Lake. In meeting this objective, the fishway has had limited success. The fishway passes relatively small numbers of pike, and then only after they have already spawned. Poor passage rates by northern pike through Denil fishways have been reported by numerous researchers (Tomich *et al.* 1982; Fernet 1984; Halstead 1984; Schwalme *et al.* 1985; Larinier 1990; Katopodis *et al.* 1991; Orr 1993). According to Collins and Gillis (1985), the general guide to assessing the success of a fishway is that it must pass at least 80% of the fish which want to pass. Based on this guideline, the Cowan Dam standard Denil fishway appears to be moderately successful in passing white suckers, but passed northern pike with poor success. Passage success for walleye and longnose suckers is unknown but is suspected to be fairly good, as neither of these species appeared to have problems ascending the fishway.

The two-level modification reduced estimated water velocities within the fishway by about two and one half times those found within a standard design Denil, and proved to be as self-cleaning as the standard Denil. After two years of operation the plywood upper level was removed, and no major debris of any type was found lodged beneath it in the lower level. The shallower depth of the two-level fishway appeared to pass northern pike better, and white suckers and longnose suckers equally as well as the standard Denil. Walleye passage however, appears to be adversely affected by the two-level design, perhaps due to shallow fishway flows preventing them from swimming deep to avoid bright sunlight.

Clearly the two-level design was not entirely successful. Although fish appeared to use the upper level of the fishway with few problems, only five percent of fish used the lower level of the fishway in 1992. It is possible that fish preferred the upper level fishway due to higher light levels within it. The lower level of the fishway was almost totally blocked from light by the floor of the upper level. Fish that require vision to successfully navigate the turbulent flows within the Denil fishway would likely have had difficulty in ascending the lower level.

Based on the low percentage of fish that ascended the lower level, there appears to be little point in installing two-level fishways in standard Denils with excessive water velocities. A possible solution for proposed new Denil fishways where d/b ratios would be in excess of 3.0, would be to construct an adjustable standard Denil fishway in a simple baffleless flume. The flume beneath the adjustable Denil would carry additional water for attraction flows. The Denil fishway itself could be constructed so that it could be raised or lowered relative to the floor of the flume. In this way, regardless of lake or tailwater levels, the fishway could be raised or lowered so that it was always positioned at the proper depth for fish passage, thus avoiding excessive water velocities. It would also be possible to experiment with this design to determine the most suitable combination of fishway depth, velocity and slope for pike passage.

CONCLUSIONS

Fish Species

General: Six species of fish utilized the Cowan Dam Denil fishway in 1990: northern pike, walleye, white suckers, longnose suckers, cisco and lake whitefish. These fish likely originated in the lower Beaver River or in Lac Ile-a-la-Crosse, 150 to 200 river km downstream of Cowan Dam. More fish of all species (with the possible exception of cisco and lake whitefish) ascended the fishway in 1985 when tailwater levels were high, than in 1990 under low flow conditions. None of the fish species that used the fishway appeared to have any difficulty locating the fishway entrance as fish passage was not related to attraction flows. Fish movement through the fishway was not related to changes in total hydraulic head between the lake and tailwater levels either.

Tag returns by anglers and the commercial fishery at Lac-Ile-a-la-Crosse suggest that fish that ascend the Cowan River to Cowan Dam in the spring originate in Lac Ile-a-la-Crosse. While they may scatter throughout the Cowan, Beaver, and associated systems during the spring and summer, they eventually return to Lac Ile-a-la-Crosse before the Beaver and Cowan Rivers become anoxic in early winter.

Northern pike: Most northern pike did not ascend the fishway until late May and early June, well after spawning had been completed below the dam. Large areas of suitable pike spawning habitat are located along the margins of the Cowan River. Northern pike did not appear to congregate below the dam for foraging purposes. Northern pike sampled below the dam were longer than pike that ascended the fishway, with smaller pike attempting to ascend the fishway more often than larger pike. Pike appeared to ascend near the water surface within the fishway, where the water velocities were fastest. The mean length of northern pike ascending the fishway declined over the period of fish movement, and as water velocities within the standard Denil fishway declined.

Northern pike took substantially longer on average to ascend the fishway after tagging than did white suckers. According to Petersen mark-recapture estimates, 1502 northern pike were present in the tailwater pool, of which only 181 (12.1%) ascended the fishway. Anglers harvested almost 20% of northern pike in the tailwater pool in 1990. From tag returns by anglers, it appears that pike that spawn below Cowan Dam in the spring disperse widely throughout the Beaver River and connecting lake and river systems after spawning is completed.

The number of pike ascending the fishway was weakly correlated with increasing water velocities in both the standard and two-level Denils. The number of pike using the fishway declined as water velocities increased. The two-level Denil fishway appeared to pass northern pike more successfully than did the standard Denil fishway under similar low-tailwater conditions.

<u>Walleye</u>: The primary motivation for walleye passage through the fishway appeared to be completion of their spawning migration. Over 90% of walleye that used the fishway were in pre-spawning condition. Peak daily movement of walleye occurred during late afternoon and early evening. Walleye did not appear to have any difficulties in ascending the standard Denil fishway in 1990. They did, however, appear to have some difficulties in ascending the two-level Denil in 1991. This may be due to excessively shallow water in the two-level Denil.

Anglers and commercial fishermen harvested an estimated 16% of walleyes that ascended the Cowan Dam fishway. Walleye that ascend the fishway do not remain in Cowan Lake, but return downriver within one month. Based on recapture locations, it appears that walleye which ascend the Cowan River to spawn are part of a much larger population that inhabits Lac Ile-a-la-Crosse and the Beaver River system.

White sucker: White suckers did not ascend the fishway in 1990 in order to complete their spring spawning migration. Only 29% of white suckers ascended the fishway prior to spawning. The remaining mature fish spawned downstream of the dam before they passed through the fishway. There is no satisfactory explanation why most white suckers waited until after spawning to ascend. In 1990, the tailwater pool is estimated to have contained 6854 white suckers, of which 58.8% ascended the fishway. The length of both pre-spawning and spent female white suckers ascending the fishway declined as the season progressed. This is likely due to older, larger fish maturing and migrating earlier than young, smaller fish. Tagged white sucker recaptures reported from the commercial fishery at Lac Ile-a-la-Crosse suggest that white suckers that spawn below Cowan Dam likely originate there.

The two-level Denil fishway studied in 1991 appeared to pass white suckers equally as well as the standard Denil fishway did in 1990.

Longnose sucker: Longnose suckers used the fishway to complete their upstream spawning migration. Almost 98% of longnose suckers that ascended the fishway did so prior to spawning. A few were observed spawning in the pool below the dam. Longnose suckers appeared to ascend the standard and two-level Denil fishways without obvious difficulty or delay. Longnose suckers which ascended the fishway into Cowan Lake did not remain there, but returned back downriver within one month of spawning.

Cisco and lake whitefish: Cisco and lake whitefish both migrated up the Cowan River to Cowan Dam and ascended the standard Denil fishway into Cowan Lake without problem. Both species are thought to have followed the spawning migrations of spring spawning species, in order to prey on fish eggs and newly hatched fry.

Denil fishway

The standard Denil fishway appears to provide good passage of walleye, white suckers and longnose suckers, and poor passage of northern pike, however, it does not appear to be having any noticeable beneficial effect on fish stocks in the area. Northern pike spawn downstream of the dam and only ascend the fishway in minor numbers. Although pre-spawning walleye and longnose suckers ascend the fishway, test netting by Saskatchewan Environment and Resource Management, Fisheries Branch has not shown any marked increase in walleye or longnose sucker populations in Cowan Lake. In fact, tag returns show that most walleye leave Cowan Lake within a month of ascending the fishway. The same is thought to occur with longnose suckers. Large numbers of pre- and post-spawning white suckers ascend the fishway, however Cowan Lake already supports a large population of this species.

The two-level Denil design was not entirely successful either, although it reduced water velocities in the fishway by about 2½ times those of a standard Denil. The two-level Denil appeared to pass northern pike better than did the standard Denil, and white and longnose suckers as well as the standard Denil. The two-level Denil appeared to cause problems for walleye passage.

Although the fishway provided fish with a choice of levels to ascend, they chose the upper level 95% of the time. A possible explanation is that there may have been insufficient light in the lower level for fish to ascend due to blocking by the upper level fishway floor.

RECOMMENDATIONS

1. Spring water releases at Cowan Dam should be held as stable as possible in order to avoid stranding of pike eggs and fry in the flooded areas below the dam.

2. For purposes of fisheries management, the Beaver and Cowan Rivers and Lac Ile-a-la-Crosse should be considered one system.

3. Because of high walleye harvests by anglers and commercial fishermen, the Cowan River should be used sparingly, if at all, as a source of walleye eggs for spawn taking purposes.

4. Until the problem of low pike usage has been resolved, Denil fishways should not be installed in locations where pike are the primary target of passage, especially if there are suitable pike spawning areas downstream.

5. On future Denil fishway installations, the height of the lower fishway entrance gate should be increased so that it can be raised clear of the water under moderate tailwater conditions. This would provide better attraction flows at the surface instead of a submerged entrance. A surface discharge might help to attract more fish, especially pike.

6. Future Denil fishways should be constructed with larger resting pools to reduce the disorienting effect that excessive turbulence has on fish, especially northern pike.

7. Two-level Denil fishways warrant further field testing, but under greater flow depths. It may have potential for improving fish passage in fishways where water velocities are excessive due to fishway water depths being greater than d/b = 4.

8. Further work should be undertaken to determine whether the development of an adjustable depth Denil fishway is viable. The proposed fishway flume would be adjustable up or down to maintain the most effective combination of water depth, water velocity, and fishway slope for a particular species. Beneath the fishway, the remaining flume depth would be used to carry additional attraction flows. The fishway could be operated with a d/b ratio of 3.0 early in the season for walleye and longnose sucker passage, and with a d/b ratio between 2.0 and 2.5 for northern pike passage later in the spring.

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Appendix 1. Summary of fishways* located in the Prairie Provinces and fish species passed.

Alberta

Fishway location	Fishway type	Year studied & reference ( )	Species passed (in order of abundance)
Beaverlodge River	Standard Denil		
Belly River	Vertical slot	Not studied	
Bolloque Lake	Pool & weir	Not studied	
Bow River (Carsland Dam)	Vertical slot	1979 (1)	brown trout, rainbow trout, rocky mountain whitefish, northern pike, white sucker, longnose sucker **(not in order).**
Bow River (Carsland Dam)	Vertical slot	1981 (2)	rocky mountain whitefish, longnose sucker, white sucker, brown trout.
Bow River (WID Weir)	Vertical slot	1981 (2)	No fish successfully passed.
Cadotte Lake	Standard Denil	Not studied	
Cross Lake	Pool & weir	Not studied	
Driedmeat Lake	Pool & weir	1979 (3)	white sucker, northern pike
Ethel Lake	Standard Denil	Not studied	
Fawcett Lake	Pool & weir	1979 (4)	white sucker, longnose sucker, northern pike, walleye.
Fawcett Lake	Standard Denil	1982 (5)	white sucker, northern pike, longnose sucker, Arctic grayling, rocky mountain whitefish.
Fawcett Lake	Standard Denil	1983 (6)	white sucker, northern pike, longnose sucker, walleye, rocky mountain whitefish.
Gregoire Lake	Pool & weir	1977, 1978 (7)	northern pike, white sucker, longnose sucker, walleye, Arctic grayling.
Hangingstone River	Pool & weir	Not studied	
Lesser Slave River	Standard Denil (10% slope)	1984 (8)	northern pike, white sucker, burbot, longnose sucker, lake whitefish, cisco, yellow perch.
	Standard Denil (20% slope)	1984 (8)	northern pike, burbot, white sucker, longnose sucker, yellow perch, lake whitefish, cisco, walleye.
	Vertical slot	1984 (8)	spottail shiner, longnose sucker, yellow perch, white sucker, northern pike, trout-perch, burbot, lake whitefish, cisco.
Iosegun Lake	Standard Denil	Not studied	

Alberta - continued

Fishway location	Fishway type	Year studied & reference ( )	Species passed (in order of abundance)
Manatokan Lake	Standard Denil	Not studied	
McCullough Lake	Standard Denil	Not studied	
Moose Lake	Vertical slot	Not studied	
Oldman River	Vertical slot	1984 (9)	few fish passed
Parlby Creek (Carlyle)	Standard Denil	1992 (9)	study was inconclusive
Parlby Creek (Spotted Lake)	Standard Denil	1992 (9)	few fish passed
Riviere des Rochers	Standard Denil		
Riviere des Rochers	Vertical slot		
Steel Lake	Pool & weir	1982 (3)	northern pike, white sucker
Sturgeon Lake	Vertical slot		
Swan River Weir	Steeppass		
West Prairie River	Pool & weir	Not studied	

Manitoba

Fishway location	Fishway type	Year studied & reference ( )	Species passed (in order of abundance)
Birch River (Bracken Dam)	Vertical slot	1983, 1984 (10)	northern pike, white sucker, walleye, common carp.
Fairford River	Standard Denil	1987 (11)	white sucker, walleye, sauger, cisco, shorthead redhorse, common carp, burbot, lake whitefish, freshwater drum, longnose sucker, silver redhorse, quillback, channel catfish.
Little Sask. River (Rapid City Dam)	Notched check weirs (rock)	Not studied	
Mossy River Dam (Lake Dauphin)	Pool & weir	Not studied	
Red River (Lockport)	Pool & weir	Not studied	
Rocky Creek Dam	Vertical slot	Not studied	
Roseau River (Dominion City)	Notched check weirs (rock)	Not studied	
Wilson Marsh	Steeppass	1981 (2)	northern pike

Saskatchewan

Fishway location	Fishway type	Year studied & reference ( )	Species passed (in order of abundance)
Assiniboine River (Kamsack)	Standard Denils	Not studied	
Cowan Lake	Weir-pool-orifice	Not studied	
Cowan Lake	Standard Denil	1985 (11)	white sucker, longnose sucker, northern pike, walleye.
Cowan Lake	Standard Denil	1990, 1991 1992 (12)	white sucker, longnose sucker, northern pike, walleye, cisco lake whitefish.
Katepwa Lake	Aeroceanics	1978 (13)	white sucker, shorthead redhorse, common carp, northern pike, walleye, cisco, lake whitefish.
Katepwa Lake	Vertical slot	1980, 1981 1982 (13)	white sucker, shorthead redhorse, common carp, walleye, northern pike, cisco.
Leaf Lake	Standard Denil	Not studied	
Nut Lake	Standard Denil	Not studied	
Round Lake	Vertical Slot	Not studied	
Siisiip Marsh (Cumberland Delta)	Standard Denil	1990 (14)	northern pike
Siisiip Marsh (Cumberland Delta)	Steeppass	1990 (14)	northern pike

* - culvert fishways are not included.

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2. Tomich et al., 1982
3. Nelson, 1983
4. Minchau, 1980
5. Halstead, 1984
6. Fernet, 1984
7. Watters, 1980
8. Schwalme et al., 1985
9. T. Olson, personal communication
10. Derksen and Gillies, 1985
11. Katopodis et al., 1991
12. This study
13. Dunn, 1983
14. Orr, 1993

Appendix 2. Recaptures of tagged northern pike, walleye and suckers by anglers and commercial fishermen.

Species	Tagging Location*	Tag Number	Date Tagged	Date Recaptured	Days at large	Distance from tagging site (km)	Recapture Location
N. pike	DST	8671	May 1/90	May 20/90	9	0.3	Cowan Dam - Tailwater Pool
N. pike	DST	8509	April 26/90	May 21/90	25	0.3	Cowan Dam - Tailwater Pool
N. pike	TWP	8769	May 23/90	May 24/90	1	0	Cowan Dam - Tailwater Pool
N. pike	TWP	8601	May 15/90	May 25/90	10	0	Cowan Dam - Tailwater Pool
N. pike	TWP	8768	May 23/90	May 26/90	3	0	Cowan Dam - Tailwater Pool
N. pike	TWP	8740	May 25/90	May 26/90	1	0	Cowan Dam - Below Hwy. #55 Bridge
N. pike	TWP	8799	May 24/90	May 27/90	3	0	Cowan Dam - Tailwater Pool
N. pike	DST	8530	May 8/90	May 27/90	19	0.2	Cowan Dam - Below Hwy. #55 Bridge
N. pike	DST	8563	April 27/90	May 31/90	34	124	Waterhen River - Bridge on Hwy #903
N. pike	TWP	8774	May 23/90	June 2/90	10	0	Cowan Dam - Tailwater Pool
N. pike	TWP	8736	May 23/90	June 2/90	10	0	Cowan Lake - Just Above Dam
N. pike	FWC	10293	May 26/90	June 9/90	14	8	Cowan Lake - 8 km South of Cowan Dam
N. pike	FWC	10338	June 1/90	June 13/90	12	0	Cowan Dam - Tailwater Pool
N. pike	FWC	10213	May 24/90	Sept. 3/90	71	0	Cowan Lake at Cowan Dam
N. pike	DST	8573	May 8/90	Feb. 5/91	272	234	MacBeth Channel - Lac Ile-a-la-Crosse
N. pike	DST	8555	April 27/90	May 18/91	387	50	Beaver and Cowan River Junction
N. pike	FWC	9083	May 12/91	May 24/91	12	4	Cowan Lake - 4 km South of Cowan Dam
N. pike	DST	8599	April 27/90	May 30/91	399	65	Beaver River - 1 km West of Green R. Junction

* - FWC = Fishway Cage
TWP = Tailwater Pool
DST = Downstream Trap

Appendix 2. Recaptures of tagged northern pike, walleye and suckers by anglers and commercial fishermen.

Species	Tagging Location	Tag Number	Date Tagged	Date Recaptured	Days at large	Distance from tagging site (km)	Recapture Location
Walleye	FWC	10159	May 7/90	May 24/90	17	61	Beaver River - 1 km East of Hwy #155 Bridge
Walleye	FWC	10107	May 6/90	May 27/90	21	104	Beaver River at Herlen Creek Near Pagan Lake
Walleye	DST	8548	May 8/90	May 30/90	22	50	Cowan River at Beaver River Junction
Walleye	FWC	10151	May 6/90	June 4/90	29	77	Beaver River Near Beatty Lake
Walleye	FWC	10154	May 6/90	June 10/90	35	186	Mouth of Beaver River in Lac Ile-a-la-Crosse
Walleye	FWC	10197	May 7/90	June 17/90	41	186	Mouth of Beaver River in Lac Ile-a-la-Crosse
Walleye	FWC?	?	~May 6/90	~June 13/90	~38	186	Mouth of Beaver River in Lac Ile-a-la-Crosse
Walleye	FWC?	?	~May 6/90	~June 14/90	~39	186	Mouth of Beaver River in Lac Ile-a-la-Crosse
Walleye	FWC?	?	~May 7/90	~June 14/90	~38	186	Mouth of Beaver River in Lac Ile-a-la-Crosse
Walleye	FWC	10172	May 6/90	June 24/90	49	64	Beaver and Green River Junction
Walleye	FWC	10106	May 6/90	~July 31/90	~86	101	Beaver River at Grande Rapids
Walleye	FWC	10121	May 6/90	Nov. 19/90	197	210	South Bay - Lac Ile-a-la-Crosse
Walleye	FWC	9018	April 24/91	May 18/91	24	50	Cowan Lake at Big River
Walleye	FWC	9013	April 23/91	May 25/91	32	183	Beaver River - 3 km Above Lac Ile-a-la-Crosse
Walleye	DST	8538	May 9/90	May 27/91	18	156	Beaver River - 3 km Downstream of Hwy #165
Walleye	DST	8526	May 8/90	June 4/91	27	63	Beaver River - 1 km Below Green River Junction
Walleye	FWC	10305	May 30/90	Nov. 18/91	537	221	Lac Ile-a-la-Crosse - Near Halfway Point
Walleye	FWC	9119	May 17/91	May 24/92	7	64	Beaver and Green River Junction
Sucker**	?	?	May, 1990	June, 1990	~40	186	Mouth of Beaver River in Lac Ile-a-la-Crosse

** - A number of unidentified suckers were caught by commercial fishermen but no numbers were recorded.

Appendix 3. Daily fish movement through the Cowan Dam Denil fishway in 1990.

Date	Mean Fishway Water Temp.(°C)	Mean Air Temp. (°C)	Pike	Walleye	White Sucker	Longnose Sucker	Cisco	White Fish	Species Total
April 25	9.0								
April 26	5.0	-4.0	0	0	45	0	0	0	45
April 27	6.0	-1.0	0	0	0	0	0	0	0
April 28	3.0	-2.0	0	0	0	0	0	0	0
April 29									0
April 30									0
May 1	3.0	7.0	0	0	0	0	0	0	0
May 2	3.8	8.3	0	0	0	0	0	0	0
May 3	4.5	9.0	0	0	1	0	0	0	1
May 4	5.8	13.3	1	49	21	6	0	0	77
May 5	6.8	20.0	0	59	50	47	0	0	156
May 6	8.7	13.7	3	92	152	111	0	0	358
May 7	7.0	-0.5	0	39	125	243	0	0	407
May 8	6.5	4.2	0	1	0	0	0	0	1
May 9	8.0	10.7	0	0	44	127	0	0	171
May 10	8.0	4.7	1	0	267	394	0	0	662
May 11	8.5	7.3	0	0	38	61	0	0	99
May 12	9.0	8.3	0	0	98	49	0	0	147
May 13	10.3	12.0	0	0	89	25	0	0	114
May 14	10.7	11.3	1	0	99	7	0	0	107
May 15	10.5	9.7	0	0	125	2	0	0	127
May 16	10.7	8.7	0	0	114	0	0	0	114
May 17	12.2	14.7	0	0	60	3	0	0	63
May 18	12.0	6.3	0	0	85	1	0	0	86
May 19	11.8	9.0	0	0	25	0	0	0	25
May 20	13.0	13.0	0	0	771	1	0	0	772
May 21	13.8	14.3	2	0	481	3	0	0	486
May 22	15.3	19.0	2	0	414	5	0	0	421
May 23	15.7	19.3	3	0	41	0	0	0	44
May 24	16.5	21.3	4	0	49	0	0	0	53
May 25	16.8	21.8	13	1	115	0	0	0	129
May 26	18.0	21.3	18	1	54	0	0	0	73
May 27	19.3	24.0	7	1	98	0	0	0	106
May 28	19.8	18.8	14	1	41	0	8	7	71
May 29	19.7	21.3	15	2	54	0	8	2	81
May 30	18.7	22.0	14	5	73	0	4	0	96
May 31	19.3	22.3	11	1	19	0	6	0	37
June 1	18.0	10.3	26	1	52	0	0	0	79
June 2	16.7	9.3	24	1	190	1	82	3	301
June 3	17.0	12.7	11	0	45	1	3	0	60
June 4	16.0	11.0	6	3	67	1	1	0	78
June 5	16.8	17.8	5	3	29	0	1	0	38
Total			181	260	4031	1088	113	12	5685

Appendix 4. Water velocity and discharge at station C (upper level) in Cowan Dam Denil fishway in 1990.

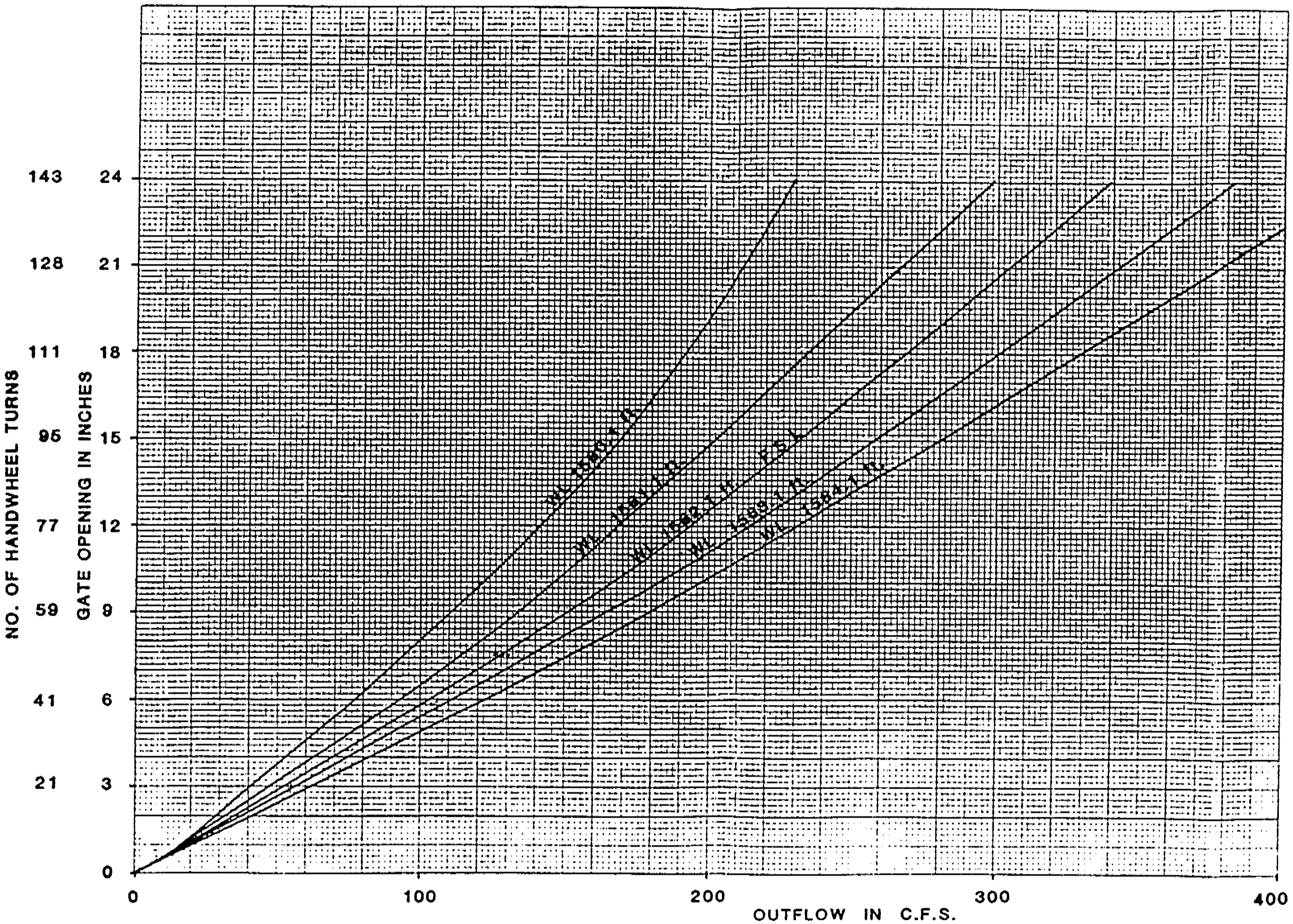
Date	Time	Water Depth d (m)	d/b	Discharge Q (cu.m/s)	Velocity at 20% depth (m/s)	Velocity at 40% depth (m/s)	Velocity at 60% depth (m/s)
April 26/90	6:00 PM	1.116	3.000	0.794	0.859	1.241	1.586
April 27/90	7:15 PM	1.111	2.987	0.787	0.854	1.234	1.578
April 28/90	3:30 PM	1.096	2.946	0.766	0.840	1.214	1.552
April 29/90							
April 30/90							
May 1/90	3:00 PM	1.116	3.000	0.794	0.859	1.241	1.586
May 2/90	3:00 PM	1.101	2.960	0.773	0.845	1.221	1.560
May 3/90	3:00 PM	1.066	2.866	0.724	0.812	1.173	1.500
May 4/90	2:50 PM	1.051	2.825	0.704	0.798	1.153	1.474
May 5/90	2:45 PM	1.021	2.745	0.664	0.770	1.113	1.423
May 6/90	2:40 PM	1.046	2.812	0.697	0.793	1.147	1.466
May 7/90	3:00 PM	1.001	2.691	0.639	0.752	1.087	1.389
May 8/90	3:30 PM	0.976	2.624	0.607	0.729	1.054	1.347
May 9/90	3:00 PM	0.946	2.543	0.570	0.702	1.014	1.297
May 10/90	2:50 PM	0.901	2.422	0.517	0.661	0.956	1.222
May 11/90	3:00 PM	0.956	2.570	0.582	0.711	1.027	1.313
May 12/90	2:50 PM	0.936	2.516	0.558	0.693	1.001	1.280
May 13/90	3:00 PM	0.991	2.664	0.626	0.743	1.074	1.372
May 14/90	3:00 PM	0.981	2.637	0.613	0.734	1.060	1.355
May 15/90	3:05 PM	1.011	2.718	0.651	0.761	1.100	1.406
May 16/90	7:00 PM	1.026	2.758	0.671	0.775	1.120	1.432
May 17/90	3:00 PM	1.016	2.731	0.658	0.766	1.107	1.415
May 18/90	2:20 PM	0.986	2.651	0.620	0.738	1.067	1.364
May 19/90	3:00 PM	0.966	2.597	0.595	0.720	1.041	1.330
May 20/90	3:05 PM	1.056	2.839	0.711	0.803	1.160	1.483
May 21/90	3:00 PM	1.051	2.825	0.704	0.798	1.153	1.474
May 22/90	3:00 PM	1.061	2.852	0.717	0.807	1.167	1.491
May 23/90	3:20 PM	1.131	3.040	0.815	0.622	1.081	1.602
May 24/90	3:15 PM	1.091	2.933	0.759	0.835	1.207	1.543
May 25/90	3:15 AM	1.081	2.906	0.745	0.826	1.194	1.526
May 26/90	3:00 PM	1.011	2.718	0.651	0.761	1.100	1.406
May 27/90	3:00 PM	0.956	2.570	0.582	0.711	1.027	1.313
May 28/90	3:20 PM	0.946	2.543	0.570	0.702	1.014	1.297
May 29/90	3:10 PM	1.001	2.691	0.639	0.752	1.087	1.389
May 30/90	3:20 PM	1.046	2.812	0.697	0.793	1.147	1.466
May 31/90	3:00 PM	0.906	2.435	0.523	0.666	0.962	1.230
June 1/90	3:30 PM	0.851	2.288	0.462	0.617	0.892	1.140
June 2/90	3:00 PM	0.866	2.328	0.478	0.630	0.911	1.164
June 3/90	3:05 PM	0.921	2.476	0.541	0.679	0.982	1.255
June 4/90	3:10 PM	0.911	2.449	0.529	0.670	0.969	1.238
June 5/90	3:20 PM	0.881	2.368	0.495	0.644	0.930	1.189

Fishway design values = Slope = 12.6%, B = 634 mm, b = 400 mm, a = 300 mm
Fishway as built values = Slope = 12.6%, B = 620 mm, b = 372 mm, a = 300 mm

Appendix 5. Attraction flows at Cowan Dam Denil fishway in 1990.

Date	Daily mean Lake level (metres ASL)	Release Gate 1 (turns open)	Release Gate 2 (turns open)	Gates 1 & 2 Discharge (cu. m/s)	Fishway Discharge (cu. m/s)	Ratio of dam to fishway discharge
April 25/90	476.21	21	0	1.56		
April 26/90	476.24	71	0	5.38	0.79	6.78
April 27/90	476.24	71	30	7.53	0.79	9.57
April 28/90	476.22	71	30	7.53	0.77	9.83
April 29/90	476.22	90	50	10.37	0.77	13.53
April 30/90	476.22	90	50	10.37	0.77	13.53
May 1/90	476.24	90	50	10.48	0.79	13.20
May 2/90	476.21	90	90	13.14	0.77	17.00
May 3/90	476.19	120	120	16.82	0.72	23.23
May 4/90	476.17	120	120	16.65	0.70	23.65
May 5/90	476.14	90	90	12.69	0.66	19.11
May 6/90	476.17	90	90	13.03	0.70	18.69
May 7/90	476.12	120	120	16.43	0.64	25.71
May 8/90	476.11	60	50	7.99	0.61	13.16
May 9/90	476.09	60	50	7.82	0.57	13.71
May 10/90	476.05	60	0	4.16	0.52	8.05
May 11/90	476.09	50	0	3.54	0.58	6.08
May 12/90	476.09	50	0	3.54	0.56	6.34
May 13/90	476.13	50	0	3.68	0.63	5.88
May 14/90	476.12	50	0	3.68	0.61	6.01
May 15/90	476.15	50	0	3.68	0.65	5.66
May 16/90	476.15	50	0	3.71	0.66	5.61
May 17/90	476.16	40	20	4.45	0.66	6.76
May 18/90	476.13	40	30	5.01	0.62	8.08
May 19/90	476.17	40	30	5.07	0.60	8.52
May 20/90	476.20	40	50	6.68	0.71	9.40
May 21/90	476.19	40	80	8.84	0.70	12.55
May 22/90	476.18	40	80	8.84	0.72	12.32
May 23/90	476.25	40	80	8.98	0.82	11.02
May 24/90	476.20	40	80	8.89	0.76	11.72
May 25/90	476.21	50	100	10.11	0.75	13.57
May 26/90	476.14	50	100	9.83	0.65	15.10
May 27/90	476.11	40	80	8.55	0.58	14.70
May 28/90	476.10	40	50	6.51	0.57	11.43
May 29/90	476.15	40	50	6.63	0.64	10.37
May 30/90	476.18	40	50	6.68	0.70	9.59
May 31/90	476.06	40	50	6.40	0.52	12.24
June 1/90	476.02	0	20	1.44	0.46	3.13
June 2/90	476.03	0	0	0.00	0.48	0.00
June 3/90	476.07	0	0	0.00	0.54	0.00
June 4/90	476.06	0	0	0.00	0.53	0.00
June 5/90	476.06	0	0	0.00	0.50	0.00

Appendix 6. Discharge rating curves for radial control gates at Cowan Dam.



Appendix 7. Daily fish movement through the two-level Denil fishway in 1991.

Date	Mean Fishway Water Temp.(°C)	Mean Air Temp. (°C)	Northern Pike	Walleye	White Sucker	Longnose Sucker	Cisco	Species Total
April 22/91	6.0	10.0						
April 23/91	8.0	15.0	0	6	13	0	0	19
April 24/91	7.2	8.3	2	11	10	0	0	23
April 25/91	6.8	6.2	0	1	0	0	0	1
April 26/91	5.8	2.7	0	4	0	0	0	4
April 27/91	4.5	0.0	0	1	0	0	0	1
April 28/91								
April 29/91								
April 30/91								
May 01/91								
May 02/91								
May 03/91	4.5	8.5						
May 04/91	5.3	8.3	0	1	5	0	0	6
May 05/91								
May 06/91								
May 07/91	9.0	14.1						
May 08/91	9.5	15.2	11	9	212	32	0	264
May 09/91								
May 10/91								
May 11/91	12.5	22.3						
May 12/91	13.7	21.7	35	0	755	13	0	803
May 13/91								
May 14/91								
May 15/91								
May 16/91	15.0	18.7						
May 17/91	15.3	19.0	11	1	164	0	1	177
May 18/91								
May 19/91								
May 20/91								
May 21/91								
May 22/91	17.0	18.8						
May 23/91	16.7	14.2	15	1	25	0	0	41
May 24/91								
Total			74	35	1184	45	1	1339

Appendix 8. Water velocity and discharge at station C in the two-level Denil fishway in 1991.

		Upper Level					Lower Level					Combined
Date	Time	Water Depth du (m)	d/b	Discharge (cu. m/s)	Velocity at 40% depth (m/s)	Velocity at 60% depth (m/s)	Water Depth dl (m)	d/b	Discharge (cu.m/s)	Velocity at 40% depth (m/s)	Velocity at 60% depth (m/s)	Discharge (cu. m/s)
April 23/91	7:00 PM	0.560	1.505	0.200	0.338	0.550	0.528	1.419	0.178	0.315	0.512	0.378
April 24/91	4:15 PM	0.550	1.478	0.193	0.331	0.538	0.528	1.419	0.178	0.315	0.512	0.370
April 25/91	3:00 PM	0.550	1.478	0.193	0.331	0.538	0.528	1.419	0.178	0.315	0.512	0.370
April 26/91	3:00 PM	0.530	1.425	0.179	0.316	0.514	0.528	1.419	0.178	0.315	0.512	0.357
April 27/91	9:30 AM	0.515	1.384	0.169	0.305	0.496	0.528	1.419	0.178	0.315	0.512	0.347
May 04/91	3:00 PM			0.182	0.320	0.520	0.528		0.178	0.315	0.512	0.360
May 08/91	4:00 PM	0.560	1.505	0.200	0.338	0.550	0.528	1.419	0.178	0.315	0.512	0.378
May 11/91	3:00 PM	0.485	1.304	0.150	0.284	0.461	0.528	1.419	0.178	0.315	0.512	0.328
May 12/91	4:00 PM	0.470	1.263	0.141	0.273	0.444	0.528	1.419	0.178	0.315	0.512	0.318
May 17/91	3:00 PM	0.490	1.317	0.153	0.287	0.467	0.528	1.419	0.178	0.315	0.512	0.331
May 23/91	3:00 PM	0.450	1.210	0.129	0.259	0.421	0.528	1.419	0.178	0.315	0.512	0.307

Fishway design values = Slope = 12.6%, B = 634 mm, b = 400 mm, a = 300 mm
Fishway as built values = Slope = 12.6%, B = 620 mm, b = 372 mm, a = 300 mm

Appendix 9. Water velocity and discharge at station L (middle flume) in the Cowan Dam Denil fishway in 1991.

Date	Time	Water Depth d (m)	d/b	Discharge Q (cu.m/s)	20% depth velocity (m/s)	40% depth velocity (m/s)	60% depth velocity (m/s)
April 23/91	7:00 PM	1.022	2.747	0.593	0.687	0.993	1.269
April 24/91	4:15 PM	1.017	2.734	0.587	0.683	0.987	1.262
April 25/91	3:00 PM	1.017	2.734	0.587	0.683	0.987	1.262
April 26/91	3:00 PM	1.012	2.720	0.581	0.679	0.981	1.254
April 27/91	9:30 AM	0.987	2.653	0.553	0.659	0.952	1.216
May 04/91	7:00 PM	0.992	2.667	0.559	0.663	0.958	1.224
May 08/91	4:00 PM	1.102	2.962	0.689	0.753	1.089	1.392
May 12/91	4:00 PM	1.027	2.761	0.599	0.691	0.999	1.277
May 17/91	3:00 PM	0.812	2.183	0.374	0.519	0.750	0.959
May 23/91	3:00 PM	0.827	2.223	0.388	0.531	0.767	0.980

Fishway design values = Slope = 10%, B = 634 mm, b = 400 mm, a = 300 mm
Fishway as built values = Slope = 10%, B = 620 mm, b = 372 mm, a = 300 mm

Appendix 10. Summary of underwater video monitoring at Cowan Dam two-level Denil fishway in 1992.

Date	Time	Number of fish: Upper level	Lower level	Total
April 21/92	12:00 PM	0	0	0
April 21/92	1:00 PM	0	0	0
April 21/92	2:00 PM	0	0	0
April 21/92	3:00 PM	0	0	0
April 21/92	4:00 PM	0	0	0
April 21/92	5:00 PM	0	0	0
April 21/92	6:00 PM	0	0	0
April 21/92	7:00 PM	0	0	0
	Subtotal	0	0	0
April 26/92	12:00 PM	0	0	0
April 26/92	1:00 PM	2	0	2
April 26/92	2:00 PM	0	0	0
April 26/92	3:00 PM	0	0	0
April 26/92	4:00 PM	0	0	0
April 26/92	5:00 PM	2	0	2
April 26/92	6:00 PM	1	0	1
April 26/92	7:00 PM	0	1	1
	Subtotal	5	1	6
May 03/92	11:00 AM	2	0	2
May 03/92	12:00 PM	0	0	0
May 03/92	1:00 PM	1	0	1
May 03/92	2:00 PM	0	0	0
May 03/92	3:00 PM	6	1	7
May 03/92	4:00 PM	3	0	3
May 03/92	5:00 PM	10	0	10
May 03/92	6:00 PM	0	0	0
May 03/92	7:00 PM	7	0	7
	Subtotal	29	1	30
May 10/92	11:00 AM	0	0	0
May 10/92	12:00 PM	0	0	0
May 10/92	1:00 PM	0	0	0
May 10/92	2:00 PM	3	0	3
May 10/92	3:00 PM	1	0	1
May 10/92	4:00 PM	0	0	0
May 10/92	5:00 PM	0	0	0
May 10/92	6:00 PM	0	0	0
May 10/92	7:00 PM	1	0	1
	Subtotal	5	0	5
	Total	39	2	41

Appendix 11. Water velocity and discharge at station C in the two-level Denil fishway in 1992.

		Upper Level					Lower Level					Combined
Date	Time	Water Depth du (m)	d/b	Discharge (cu. m/s)	Velocity at 40% depth (m/s)	Velocity at 60% depth (m/s)	Water Depth dl (m)	d/b	Discharge (cu.m/s)	Velocity at 40% depth (m/s)	Velocity at 60% depth (m/s)	Discharge (cu.m/s)
April 21/92	3:00 PM	0.580	1.559	0.214	0.353	0.574	0.528	1.419	0.178	0.315	0.512	0.392
April 26/92	3:00 PM	0.615	1.653	0.241	0.450	0.652	0.528	1.419	0.178	0.315	0.512	0.419
May 03/92	3:00 PM	0.450	1.210	0.129	0.259	0.421	0.528	1.419	0.178	0.315	0.512	0.307
May 10/92	3:00 PM	0.500	1.344	0.159	0.295	0.479	0.528	1.419	0.178	0.315	0.512	0.337

Fishway design values = Slope = 12.6%, B = 634 mm, b = 400 mm, a = 300 mm
Fishway as built values = Slope = 12.6%, B = 620 mm, b = 372 mm, a = 300 mm