LEANDER:

TUTKIMUS VESISUIHKUPUMPUN SOVELTUVUUDESTA KALOJEN, LÄHINNÄ LOHIEN, PUMPPAAMISEEN VOIMALAITOSPATOJEN OHI

1976 -03- 23

Keksintösäätiö
DI Tengvall

Saatuani Keksintösäätiöltä tehtäväksi tutkia vesisuihkupumpun (eräs ejektoripumppulaji) soveltuvuutta kalojen, lähinnä lohien, pumppaamiseen voimalaitospatojen ohi joen yläjuoksulle sopiville kutupaikoille esittäisin seuraavaa:

Muutamasta lehtiartikkelista kootut tärkeimmät lisätiedot olen koonnut ranskalaisilla viivoilla alle:
-vaikka itse pumppu toimisi hyvin ja kalat saataisiin sen tai siihen liittyvien keskipakoispumppujen avulla nostetuksi joen yläjuoksulle padon ohi, saattaakin varsinaiseksi ongelmaksi nousta kalojen keräily ja houkuttelu imuputken suulle joen alajuoksulla (L2 s211). Ohjailuun voitaisiin ajatella metallilankaverkkoja tai esim sähköisiä ohjaimia (kuten laitumilla käytetty "paimenpoika")

-ajateltu vesisuihkupumppu tulisi kilpailemaan jo käytettyjen "kalatikapuiden" ja erilaisten kuljettimien kanssa tehossa ja taloudellisuudessa

-yleensä vesisuihkupumppujen laskenta ja teknilliset tiedot koskevat sellaisia tyyppejä, joissa keskipakopumpun painama käyttövesi tulee ejektoripumpun keskeltä eikä prototyypin tapaan sivulta

-tarvittavan keskipakopumpun antama energia ei mene hukkaan kokonaan, sillä pumpattu vesi menee takaisin voimalaitoksen turbiineihin ja osa sen energiasta muuttuu näin sähköksi

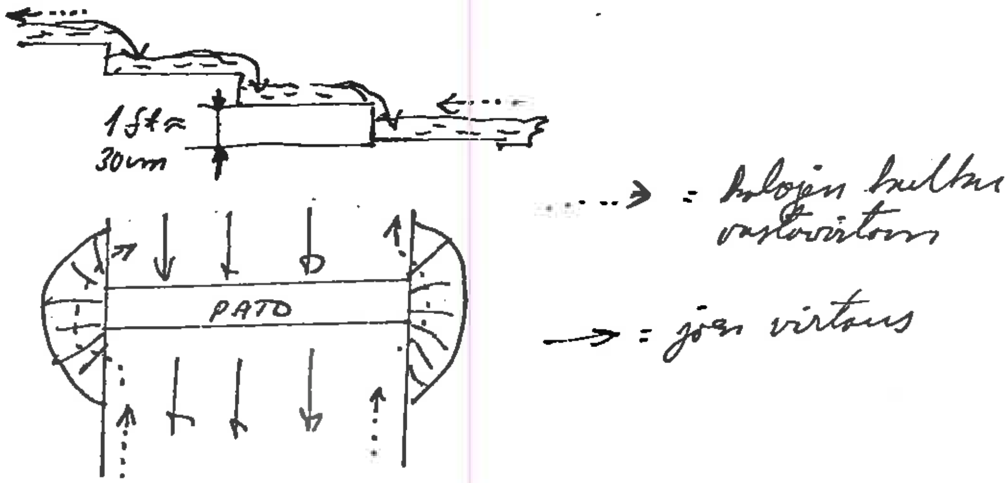
-yleensä kalat valitsevat suuremman virtausnopeuden tien kuin pienemmän (L3 s65)

-

-kala seuraa rantaviivaa, joten kalojen sisääntuloaukkoja ei tarvita padon keskellä (L1 s38)

-jättövesialtaassa on sisäänmenoaukon oltava n 180 cm vedenpinnan alapuolella (L1 s38)

-olemassaolevia kalankuljetuslaitteita ovat ainakin:
a) sähköinen kuljetin, eräänlainen kalojen raitiovaunu (L1 s38)
b) kalatikkaat (laajimmassa käytössä) (L1 s38)



-kalatikkaissa kalat lopettavat nousemisen heti pimeän tultua, mutta keskellä tikapuita olevat jatkavat yläjuoksulle saakka eivätkä pysähdy välialtaisiin (L3 s61)

-sisäänmenoaukoissa on kalan uitava vastavirtaan, jonka nopeus on n 1,2-2,4 m/s, so on käytettävä jonkinlaista houkutusvirtausta. Tähän ei yleensä käytetä patoaltaan vettä vaan erillisiä sähkömoottorilla tai turbiinilla käyviä pumppuja (L1 s38)

-jonkinlainen kalanlaskentatekniikka on tarpeen tehokkuuden kontrolloimiseksi ainakin koevaiheessa (L1 s40)

Otaniemessä 1976-08-18

J. Leander
....
J.Leander

LASKELMIA KOEPUMPUSTA:

MASSA:

otetaan kokonaispituudeksi $L = 2\ m$

jolloin

runkolevyt orot : 2 kpl 2000 × 454 × 2

2 kpl 2000 × 124 × 2

teräs $\varrho = 7{,}8\ \frac{kg}{dm^3}$ $m = \varrho \cdot V$

jolloin $M_{ROT} \approx 36\ kg$

alumiini $\varrho = 2{,}7\ \frac{kg}{dm^3}$, jolloin tulee n. 3 kertaa keveämpi laite

karkea arvio laippoineen ja tukineen on siis terästä ≈ 50 kg

alumiinia ≈ 17 kg

AJOPUMPPU:

Jos ajetaan Vesivoimalaboratorion pumpulla on nimellisarvot: $H = 5\ m$, $Q = 12000\ l/min = 200\ l/s$

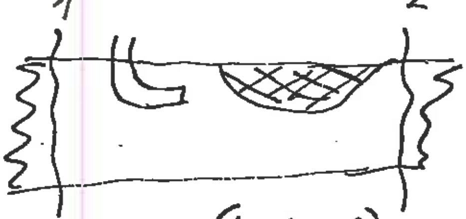
$n = 725\ 1/min$

sähkömoottori: $P = 17\ kW$ $\cos\varphi = 0{,}83$

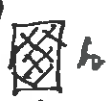
$U = 380\ V$ $\eta_{nom} = 0{,}89$

$n = 725\ 1/min$

Oheisena pumpun ominaiskäyrästö (laboratoriotyönä mitattu)



poikkipinta-ala kohdassa 2: (ks KUVA 2)



$A = b \cdot h = 12 \times 45\ cm = 550\ cm^2$

ja

$$v_{(\eta max)} = \frac{Q_{(\eta max)}}{A} = \frac{170\ l/s}{550\ cm^2} = 3{,}1\ m/s$$

jos huomioidaan vain keskipakopumpun tilavuusvirta. Todellisuudessa on yksikkölaitteessa 2 pienempi nopeus ja suurempi tilavuusvirta kuin yläarvioitu, koska vesisuihku "reippaa" pumpattavaa nestettä mukaansa ja siirtää osan energiaansa siihen.

η_{max} saavutetaan NL:n KP-pumpulla

kun $H = 7\ m$

$Q = 170\ l/s$

$P = 13{,}3\ kW$

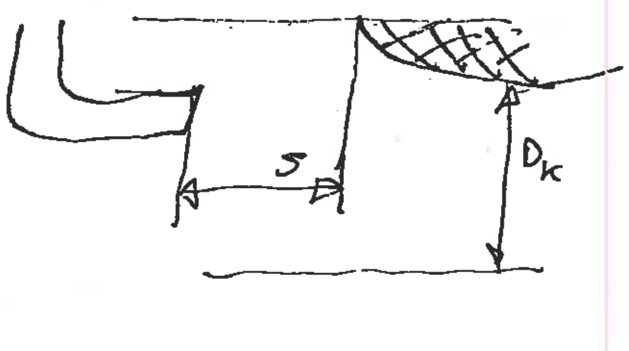
Lasketaan Reynoldsin luku ensin imuputkessa (keskipakopumppu)

ensin $v = \frac{170\ dm^3/s}{28{,}3\ cm^2} = 48\ m/s$ $\left\{ A = \pi \cdot 3^2\ cm^2 = 28{,}3\ cm^2 \right.$

$Re = \frac{\rho v D}{\mu}$; $v = 48\ m/s$; $\rho = 1000\ kg/m^3$; $D = 6\ cm$; $\mu = 1{,}307\ cP$ (10 °C vesi)

$$Re = \frac{3{,}1\ m/s \cdot 6\ cm \cdot 1000\ kg/m^3}{1{,}307 \cdot 10^{-2}\ \frac{dyn\ s}{cm^2}} = 2\ 210\ 000$$

s.o. virtaus on turbulenttinen ($Re_{kr} = 2000$)



SUUTTIMEN JA KURKUN ETÄISYYS:

$s = D_K \approx 300\ mm$

jos seurataan lähteen 3 s. 456 ohjetta

mutta kurkun asema on siirrettävä ja voidaan kokeilla paras etäisyys

KURKUN PITUUS L:

L 9.5456: $L = (5-10) \times D_K$

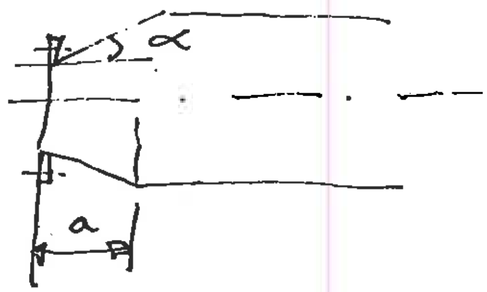
paras arvo lienee $L = 6 \times D_K$

mutta nyt kurkku on muuttuva, joten tätä ei kannattane laskea

DIFFUUSORI:

on jätetty alunperin pois mutta voidaan käyttää poistopuolen laippaa

L 9 5.456:



$\alpha \approx 4 \ldots 10°$

$a \approx (4-8) \times D_K$

SUUTTIMEN JA KURKUN PINTA-ALA SUHDE

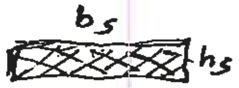
$R \approx 0{,}3$ jolla saavutetaan maxim hyötysuhde

$\frac{A_S}{A_K} = R = 0{,}3$

so. $A_S = 0{,}3 \cdot A_K = \frac{3}{10} A_K$

nyt $A_K = 30\,cm \times 12\,cm = 360\,cm^2$

$\therefore A_S = 108\,cm^2$

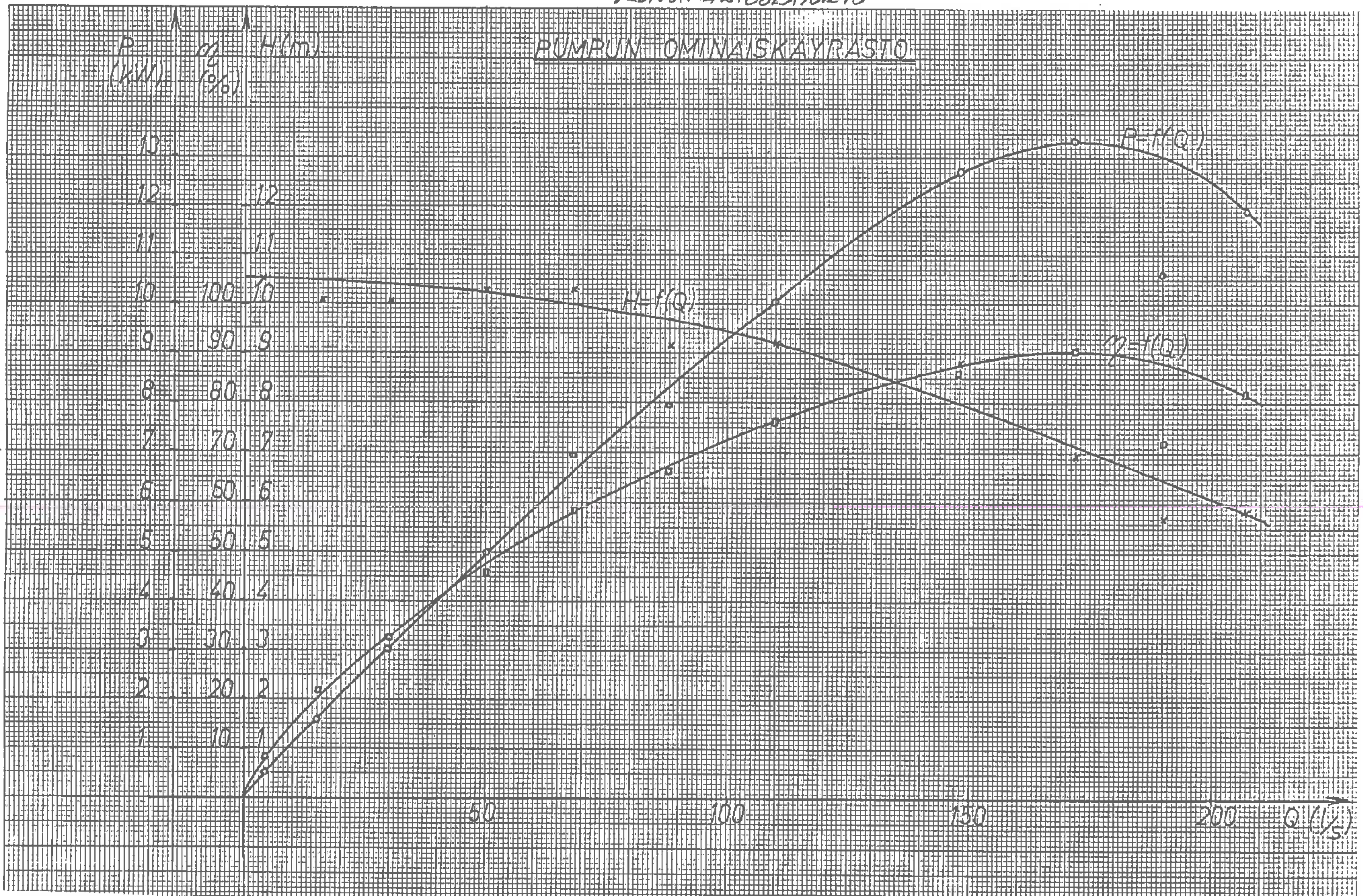


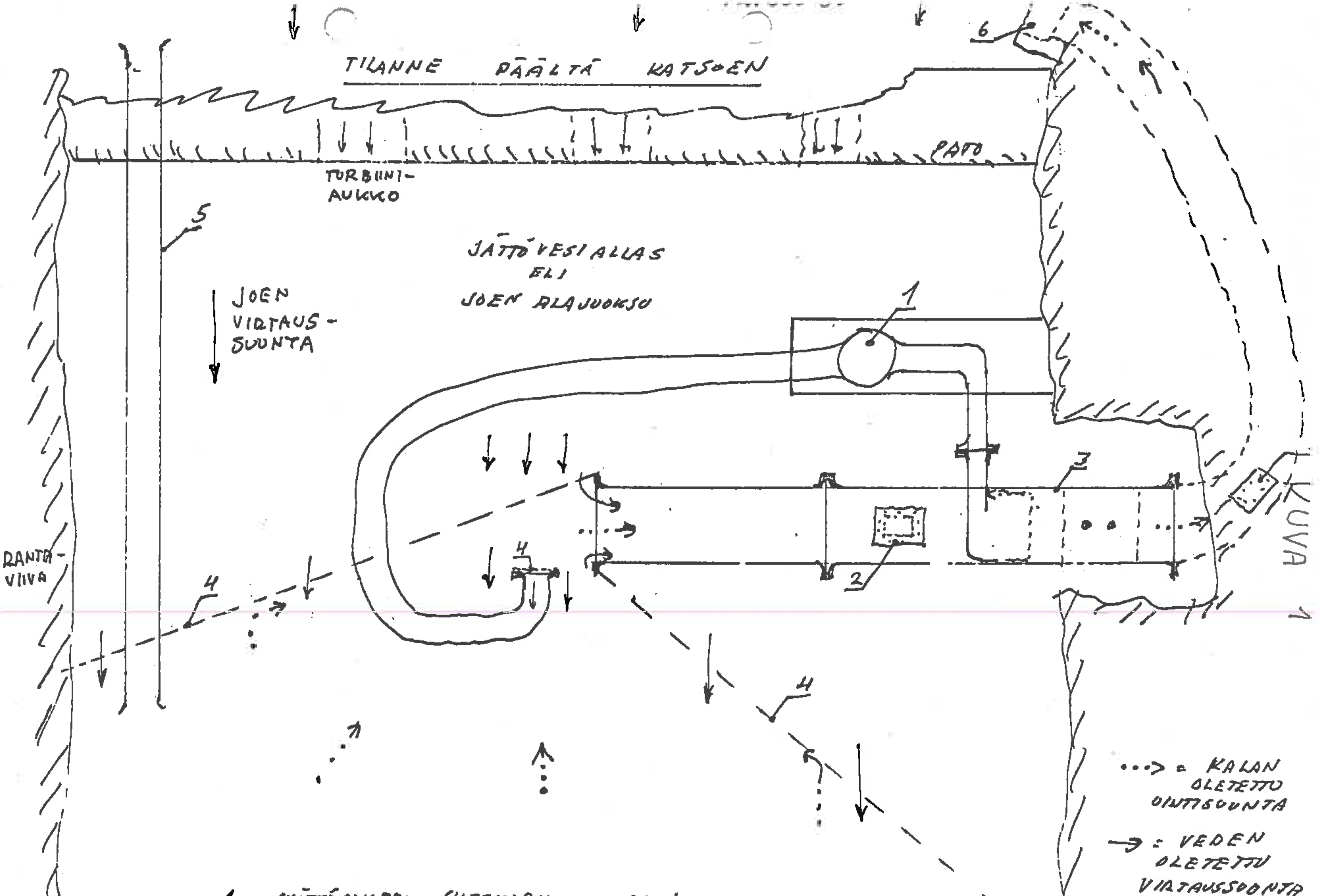
$b_S \approx 100\,mm = 10\,cm$

$\therefore$

$h_S = \frac{108}{10} = 10{,}8\,cm$

VESIVOIMALABORATORIO



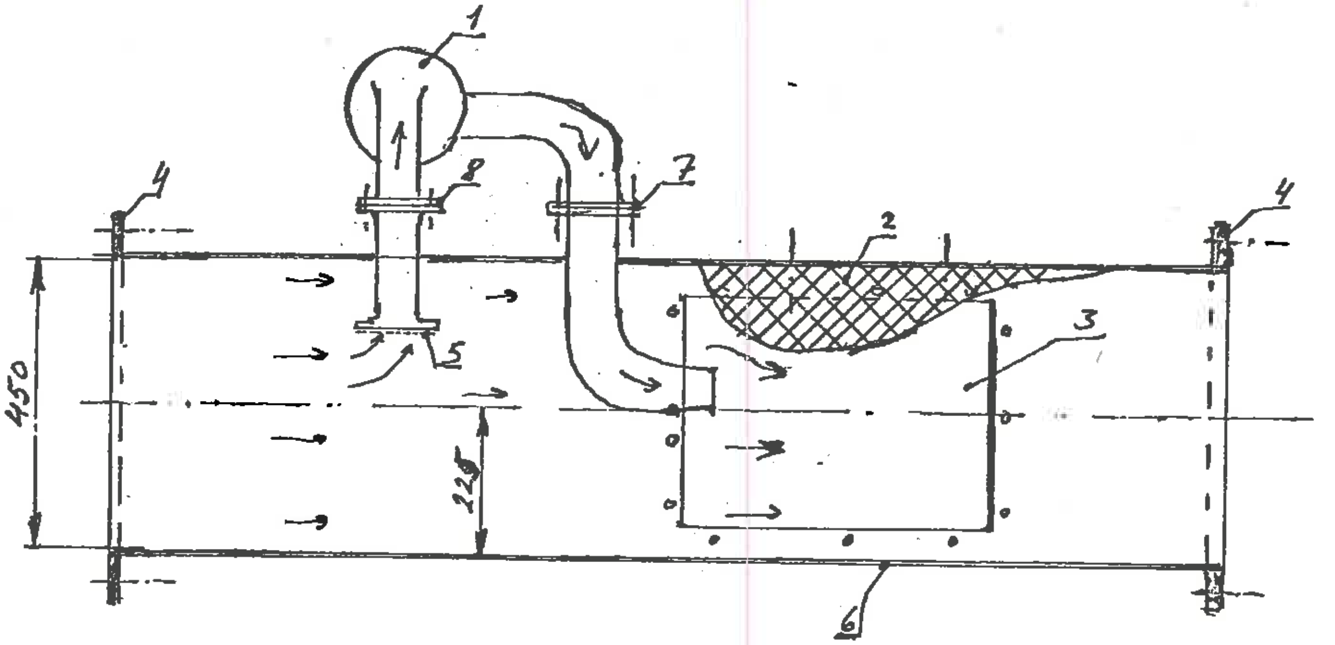


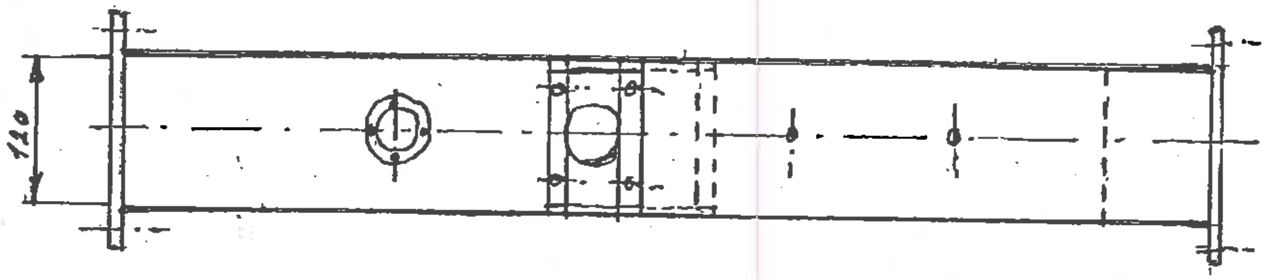
1 = SYÖTTÖPUMPPU (KESKIPAKOPUMPPU)
2 = TARKASTUSAUKKO
3 = VESISUIHKU- ELI EJEKTORIPUMPPU
4 = TIHEÄSILMÄINEN RAUTALANKAVERKKO
5 = MEREEN PALAAVIEN LOHIEN PALUUPUTKI
6 = LASKENTA- JA TARKKAILUASEMA

KUVA 2

PERIAATE PIIRROS KOEPUMPUSTA

MALLI : L9 S. 458

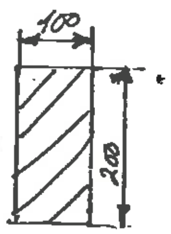




KUVA 3

IDEAALI LOHI : 10 kg PAINAVA TENOJOESSA

1:10



7: PAINEPUTKEN KIINNITYSLAIPPA

8: IMUPUTKEN KIINNITYSLAIPPA

KUVA 2, SELITYKSET

1: KESKIPAKOPUMPPU SÄHKÖ YM MOOTTOREINEEN

2: SUPISTUSKAPPALE PUUTA, MUOVIA TMS, HELPOSTI IRROITETTAVA

3: TARKKAILUPUKKO PERSPEX-KANNELLA, MOLEMMILLA SIVUILLA, KUMITIIVISTE TMS VÄLISSÄ

4: KIINNITYSLAIPAT PUTKISTOON

5: METALLIVERKKO TMS KALAN KULUN ESTÄMISEKSI

6: LAITTEEN RUNKO

KUVA 14

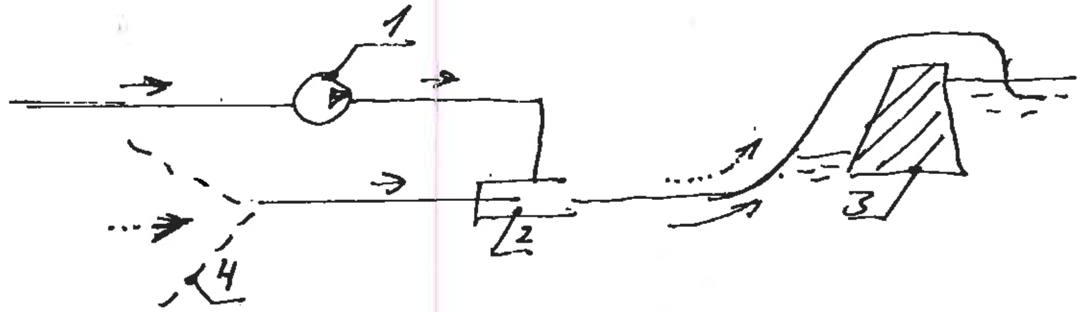
ERÄITÄ VAIHTOEHTOJA

NUMEROINTI: 1: KESKIPAKOPUMPPU
2: EJEKTORI
3: PATORAKENNELMA
4: KERÄILY- JA OHJAUSJÄRJESTELMÄ

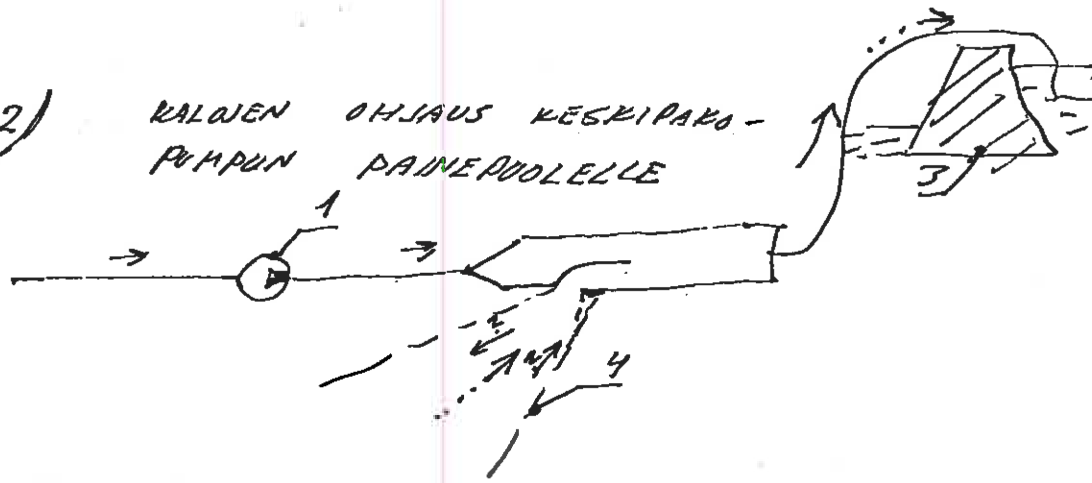
···> : KALOJEN KULKUSUUNTA

——> : VEDEN VIRTAUSSUUNTA

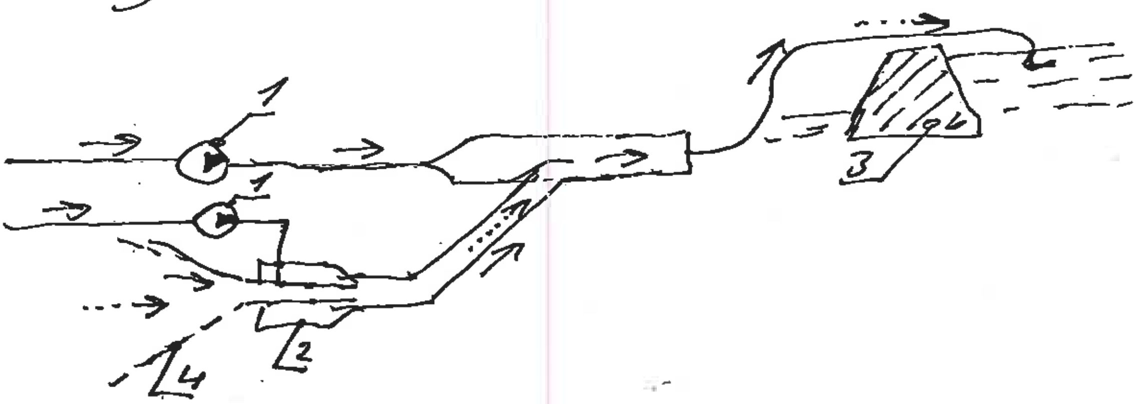
VAIHTOEHTO 1) PELKKÄ VESISUIHKUPUMPPU



VAIHTOEHTO 2) KALOJEN OHJAUS KESKIPAKOPUMPUN PAINEPUOLELLE



VAIHTOEHTO 3) YHDISTELMÄ VAIHTOEHO. 1 JA 2



X:llä verkityt mukana

LÄHDELUETTELO

Lähteet ovat saatavissa TKK:n kirjastossa Otaniemessä.

I) alaotsikolla "FISHWAYS" Engineering Indexistä vuodesta 1960 lähtien

X 1) Deurer, R.H. Pumping saves water and power in fish-passage facilities,
Civil Engineering, Nov 1960 ss 38-40

X 2) Eicher, G.J. Stream biology and hydroelectric power
Water Power, Jun 1973, ss 211-218

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3) MacLean, B.M. Model and prototype research on fish ladders
Journal of the Power Division, Jul 1961, ss 57-68

---

4) Wayne, W.W. Fish handling facilities for Baker River project
Journal of the Power Division, Nov 1961, ss 23-54

LÄHDELUETTELO

Lähteet ovat saatavissa TKK:nkirjastossa Otaniemessä.

II) alaotsikolla " PUMPS, JET" Engineering Indexistä vuodesta 1960 lähtien

5) Engel, M.O. Some problems in the design and operation of jet ejectors
The Institution of Mechanical Engineers, Proceedings, Vol 177 No 13 1963, ss 347-357

---

6) Johannesen, N.H. Ejector Theory and Experiments
Transactions of the Danish Academy of Technical Sciences, A.T.S, 1951 No1, ss 5-161 .

---

7) Kentfield, J.A.C &
Barnes, R.W. The prediction of the optimum performance of ejectors
The Institution of Mechanical Engineers, Proceedings, Vol 186 54/72, ss 671-681

---

8) Mueller, N.H.G. Water jet pump
Journal of the Hydraulics Division, May 1964, ss 83-113

X 9) Silvester, R Characteristics and applications of the water-jet pump
La Houille Blanche, No. 4, Aug-Sep 1961, ss 451-460

---

10) Silvester, R The Water-Jet Pump-Its Use in Hydro-Electric Schemes
Water Power, May 1960, ss 176-180

III) kirjat:

1) Pohlenz, W Grundlagen für Pumpen, erit. ss317-323
Berlin, 1975

RAATIKAINEN:

EJEKTORIPUMPULLA SUORITETTU ALUSTAVA KALAFYSIOLOGINEN KOE

EJEKTORIPUMPULLA SUORITETTU ALUSTAVA KALAFYSIOLOGINEN KOE

0.0 YLEISTÄ

0.1 Kokeen tarkoitus

Kehitettäessä ejektoriperiaatteella toimivaa kalaporrasta, on pidetty aiheellisena selvittää kalojen fysiologista kestokykyä nopeasti vaihtuvissa paineolosuhteissa. Tehdyn kokeen tarkoitus oli tutkia pienoislaitteistojen avulla alustavasti tammukoiden käyttäytymistä ja kestävyyttä porrasolosuhteissa, koska oletettavasti suuremmat kalat käyttäytynevät suuremmassa laitteistossa vastaavalla tavalla.

0.2 Koeolosuhteet

Paikka: Ivalojoki Ruikamutka

Aika: 12. - 14.7.1976

Laitteisto:
- ejektori halkaisija 60 mm hyperbolisella ulkokehäsyöstöllä
- ajopumppu Homelite XLS 1 1/2 - 4, teho 270 l/min.
- tarvittava muu letku, sumppu yms. kalusto

Säätila: Pysyvä korkeapaine, taivas pilvetön, päivälämpötila klo 12.00 +20°C, suhteellinen kosteus alhainen.

Vesi: Lämpötila 12.7. +15°C ja 14.7. +16°C. Vesi normaalia alhaisempi, virtaama koepaikalla 0 - 0,5 m/s. Näkyväisyys yli 4 m. Happitilanne oletettavasti normaali.

1.0 KOE KALARYHMILLÄ

1.1 Koekalat

Koekalojen pyynti tapahtui 12.7. klo 12.00 - 18.00 onkien heitto-ongella pienillä kehrälipoilla. Saalis yhteensä 46 kpl tammukoita, joista 16 kpl onginnassa haitallisesti vahingoittuneina poistettiin välittömästi koekalojen joukosta. 30 tammukkaa pantiin sumppuihin välittömästi. 13.7. poistettiin koekaloista vielä 10 tammukkaa, joista kolmella tasapainohäiriöitä ja muissa silminhavaittavia vahingoittumia tai apaattisuutta.

Kalat jaettiin kahteen kymmenen kalan ryhmään sumppuihin.

1.2 Koeajo

Arvottu kymmenen kalan koeryhmä siirrettiin säilytyssumpusta laatikkosumppuun, jonka toiseen päähän oli yhdistetty ejektorin imuputki ja toiseen päähän vettä läpäisevä ritilä. Kalat imettiin ejektorin läpi putkeen, jonka pituus oli viisi metriä. Putkesta kalat joutuivat veden mukana verkolla peitettyyn astiaan. Koeryhmä ajettiin kymmenen kertaa systeemin läpi ilman kuivakäsittelyvaiheita. Korkeusero ajossa 42 cm.

1.3 Kalojen käyttäytyminen

Kaloja jouduttiin ajamaan ejektorin imuun verraten kovakouraisestikin, koska kaikki pyrkivät melkein poikkeuksetta virtausta vastaan. Useimmat menivät ejektoriin pyrstö edellä. Tapahtui myös jonkinverran poikittaista juuttumista imuputken suulle. Tuloastiassa ei ollut havaittavissa kalojen käyttäytymisessä muutosta koekertojen lisääntyessä. Tasapainohäiriöitä ei ollut. Reagointinopeus muuttumaton.

1.4 Jälkiseuranta

Koekalat siirrettiin takaisin säilytyssumppuun. Koekalojen ja vertailuryhmän käyttäytymisen välillä ei ollut havaittavia eroja.

Koekaloja ja vertailuryhmää säilytettiin vuorokausi säilytyssumpuissa. Kumpikin ryhmä säilyi ilman kalojen kuolemista tai havaittavaa muuttumista.

1.5 Yksittäiskokeet

Koetuloksen varmistamiseksi tehtiin yksittäiskokeita yhdellä ja useammilla perättäisillä ajoilla. Myöskään näissä kokeissa ei havaittu tasapainohäiriöitä tai muuta vastaavaa häiriintymistä. Reagointi häirintään normaalia 0 - 4 sekunnin kuluttua putkesta poistumisen jälkeen.

1.6 Kuivakokeet

Kalojen kuivasiirtokestävyyden tutkimiseksi pidettiin ongittuja yksittäistammukoita eri pituisia aikoja rannalla kuivalla somerikolla. Vallinneissa olosuhteissa todettiin noin 2 minuuttia olevan raja, jota kauemmin vedestä poissa olleet tammukat eivät enää vironneet.

2.0 KOKEEN TULOS

2.1 Kalojen kestävyys

Käsitykseni mukaan tammukat kestävät hyvin ejektoripumppusiirron, joten tutkittavana olevan porrassysteemin käyttöön otto on lähinnä fysikaalinen ongelma lähinnä siten, että siirtoon käytettävä energiamäärä tulisi saada pienemmäksi ejektoriosan kehittämisellä esimerkiksi esittämäni ohivirtausperiaatteen avulla.

3.0 MUITA HUOMIOITA

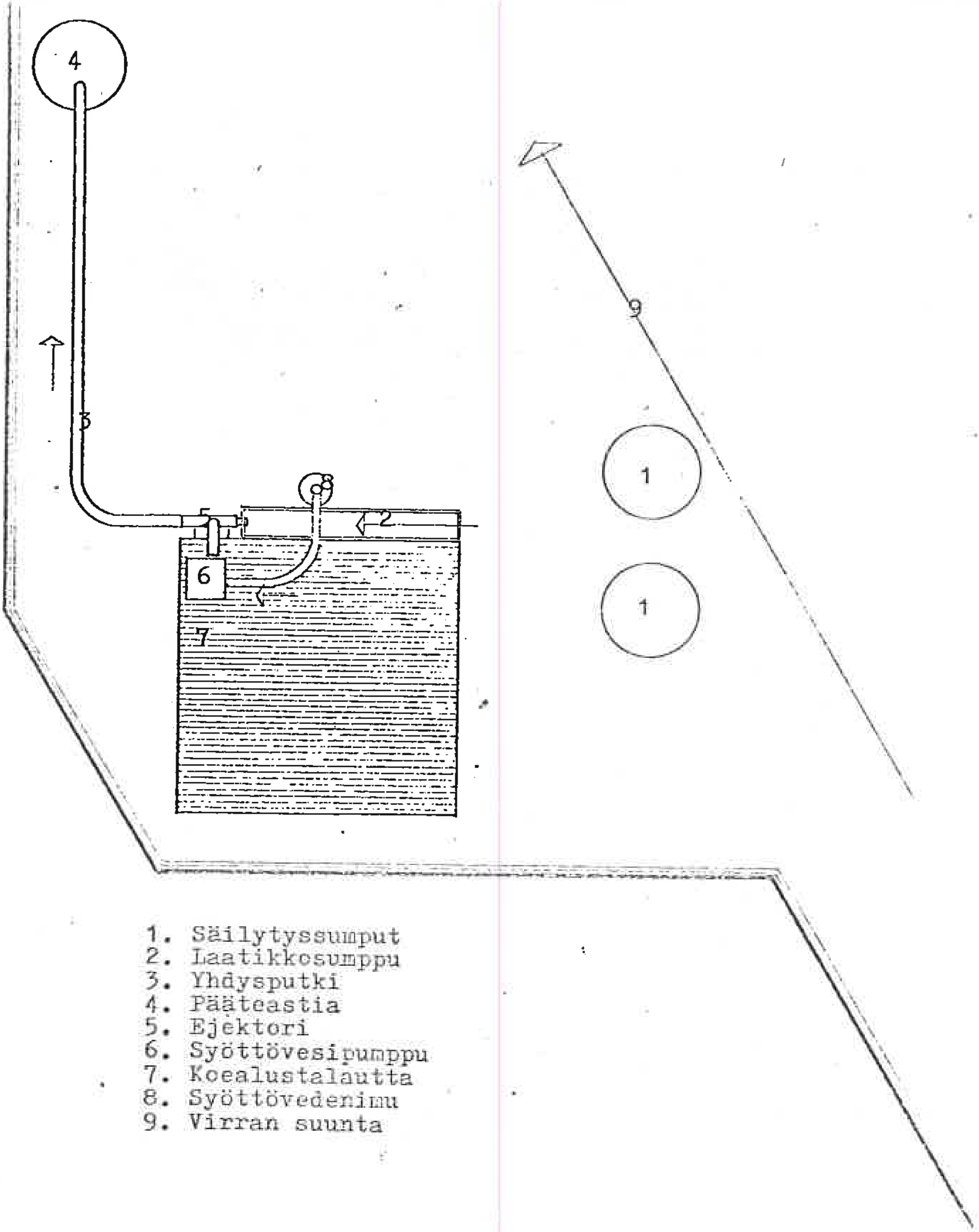
3.1 Veden hapetus

Ejektoriosan imuputken ollessa vedenpintaa lähellä, sekoittuu imettävään veteen huomattava määrä ilmaa alipaineolosuhteissa. Ejektoriperiaatetta voitanee myöskin käyttää menestyksellä veden happipitoisuuden lisäämiseen.

Martinlaakso 15.8.1976

Pentti Raatikainen

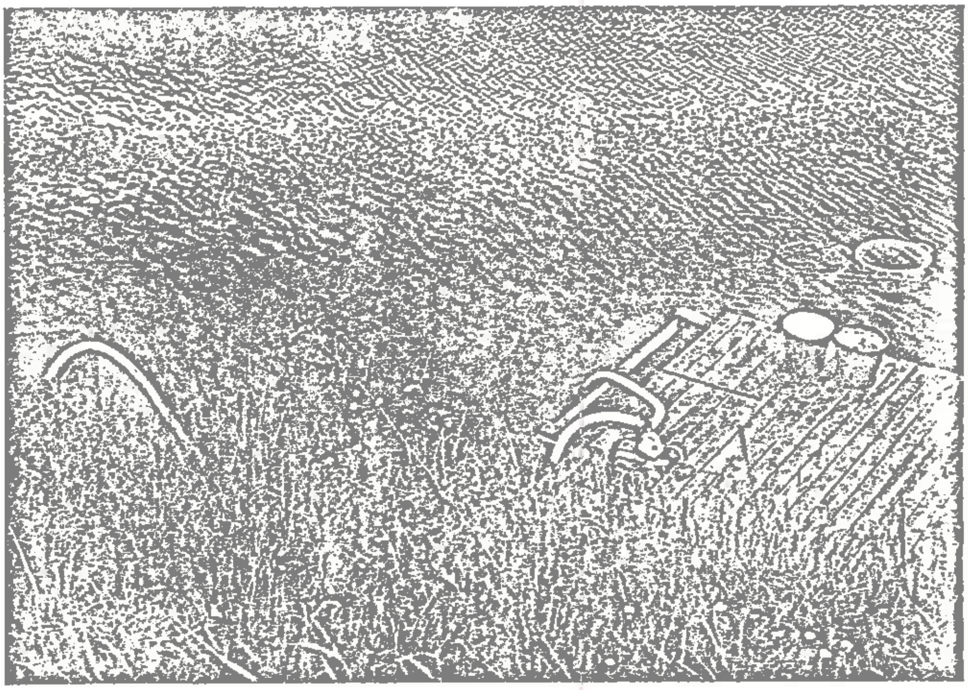
Liitteenä piirustuksia
ja valokuvia.



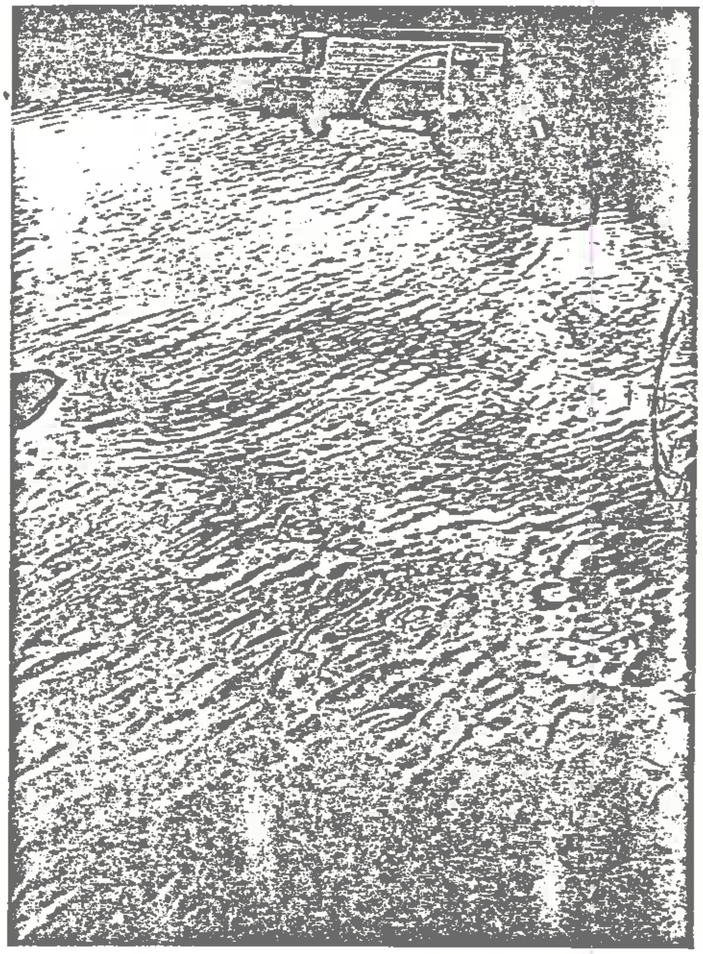
1. Säilytyssumput
2. Laatikkosumppu
3. Yhdysputki
4. Pääteastia
5. Ejektori
6. Syöttövesipumppu
7. Koealustalautta
8. Syöttövedenimu
9. Virran suunta

Koetilannekaavio 1:50

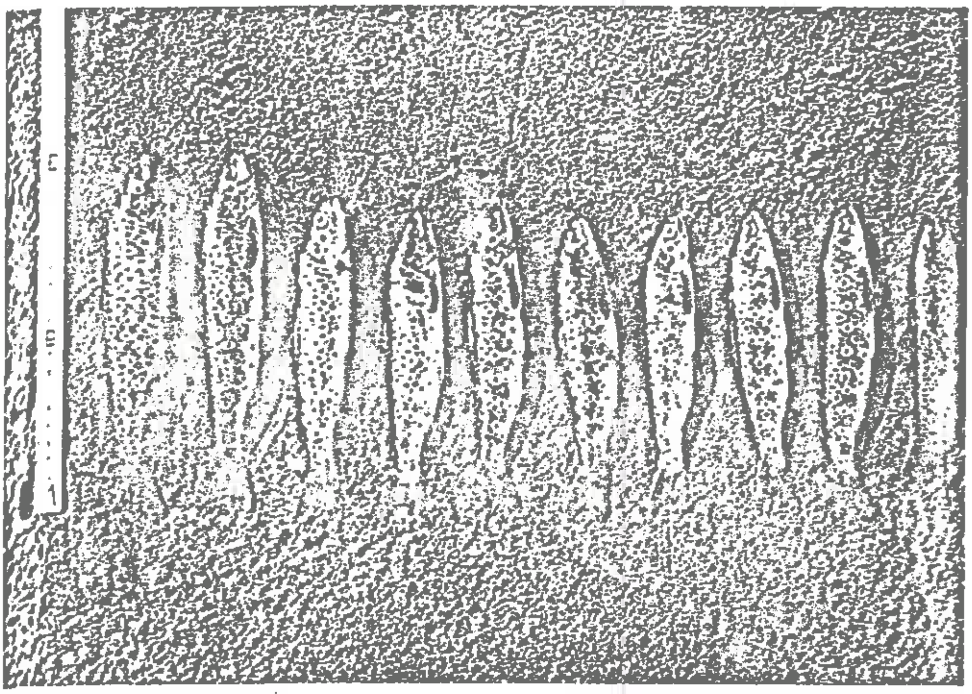
VALOKUVIA 1



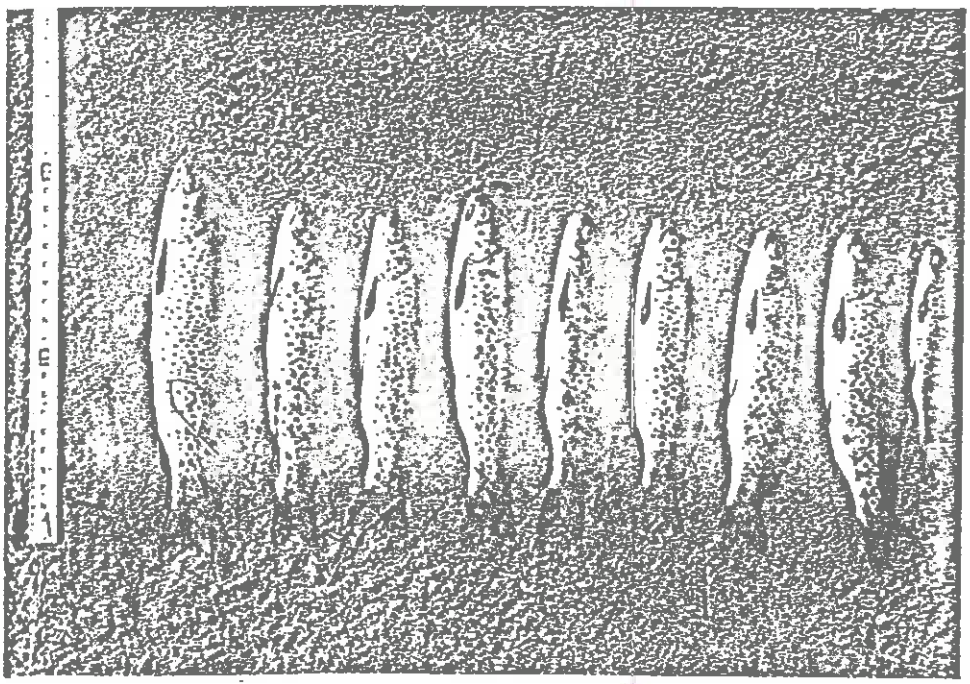
Koetilanne



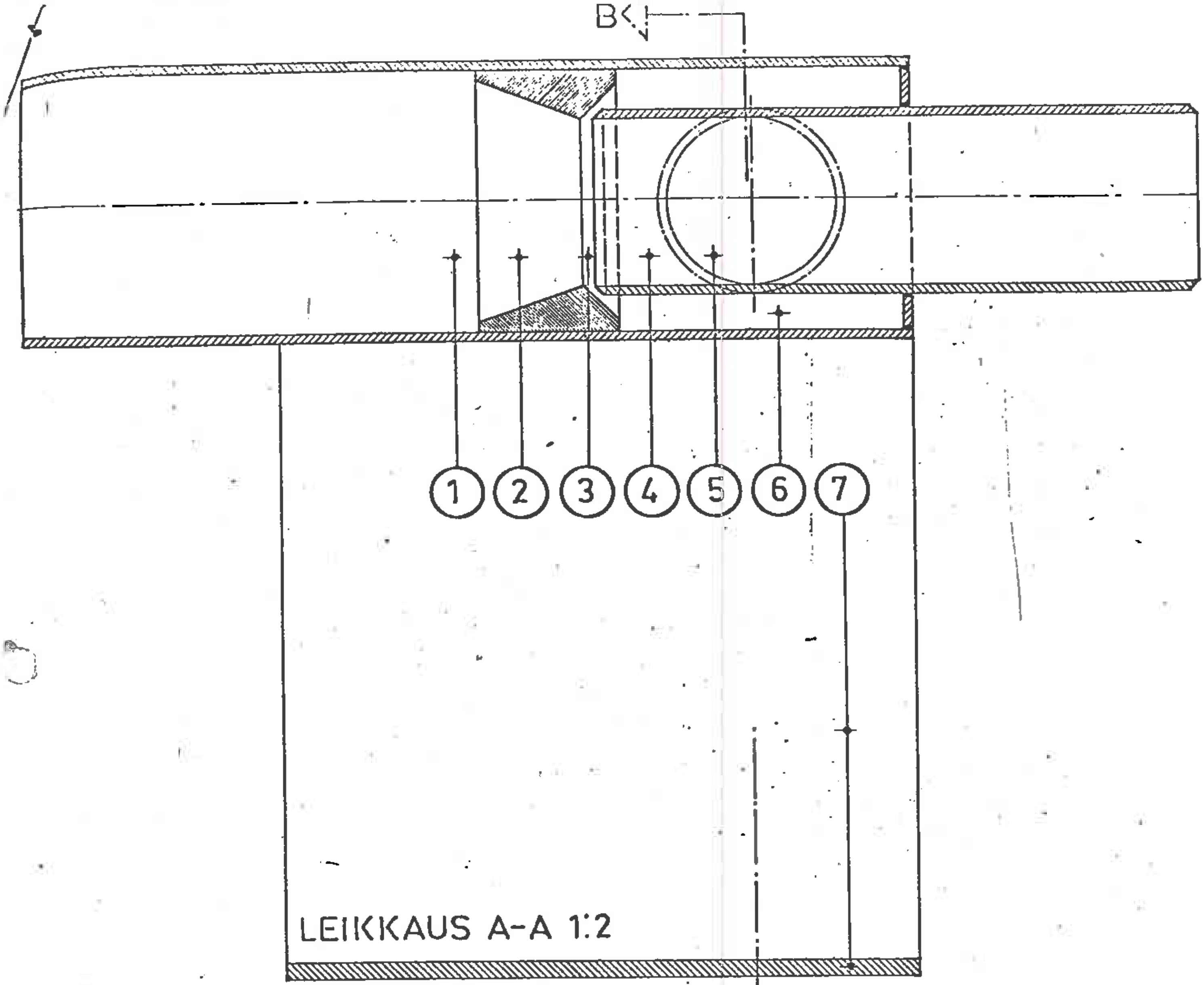
VALOKUVIA 2



Koeryhmä



Vertailuryhmä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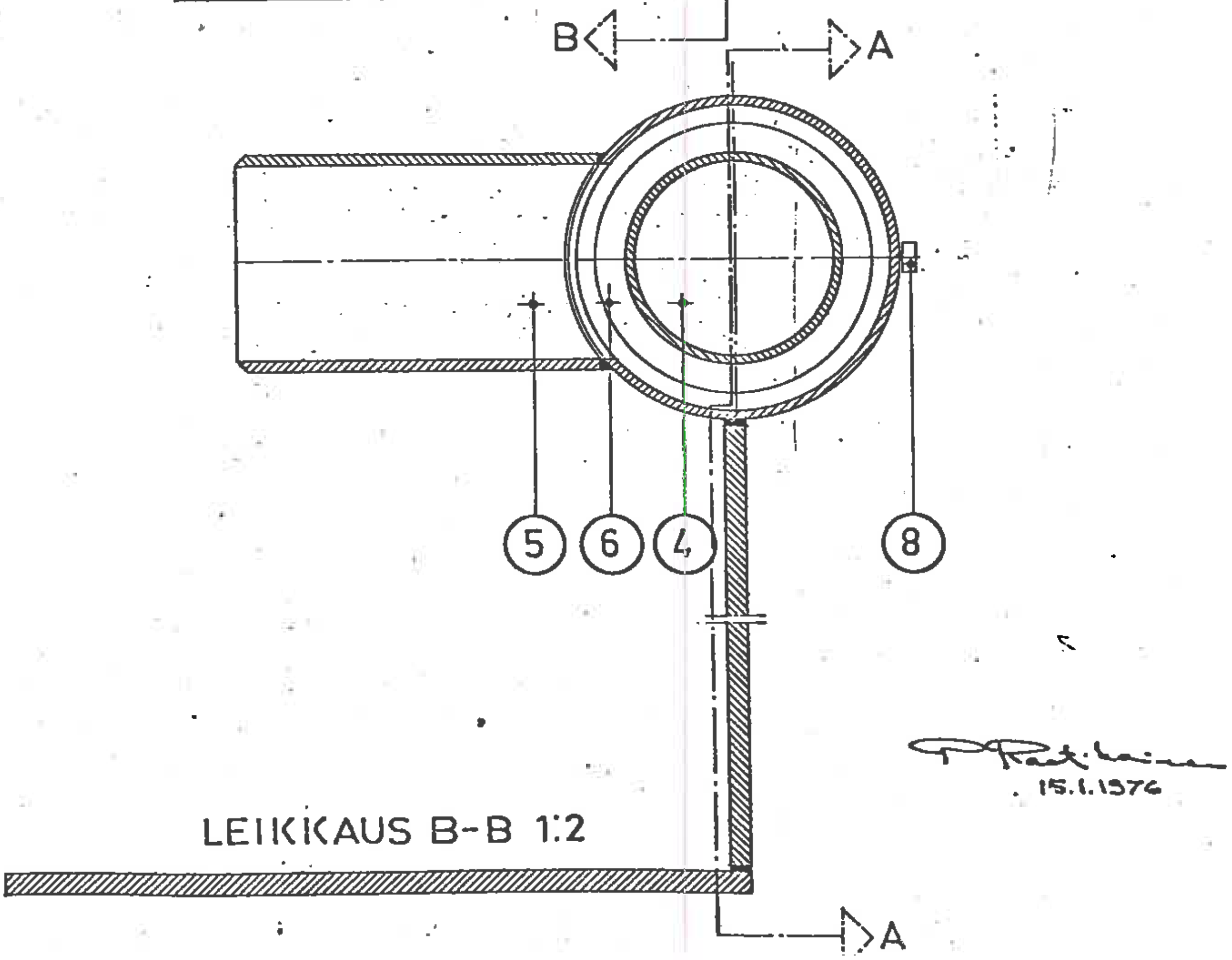
LEIKKAUS A-A 1:2


A
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15.1.1976
LEIKKAUS B-B 1:2
A

PROTOTYYPIN RAKENNESELOSTUS

Prototyyppi on valmistettu lähinnä teoreettisen toimintaperiaatteen toimivuuden empiiriseksi toteamiseksi, josta syystä rakenne virtaus-solien muotoilua myöten on verraten karkea valmistuskustannusten minimoimiseksi.

Imuveden ja syöstöveden 1. ajoveden seos poistuu poistoputken (1) kautta: Syöstöveden paine- ja määräsuhdetta on säädetty siirrettävän suutinrenkaan (2) avulla. Suutinrenkaan ja imuputken (4) välinen rako muodostaa rengasmaisen syöstövesikanavan (3), jonka syöstökulma on ollut vakio 450 ^{o} poisto- ja imuputken keskiakseliin nähden. Ajovesi on pumpattu keskipakopumpulla imuputken, suutinrenkaan ja poistoputken muodostamaan painesolaan (6). Suutinrenkaan asemaa on voitu muuttaa säätöruuvien (8) avulla. Laite on ollut kiinnitettynä jalustarakenteen (7) avulla.

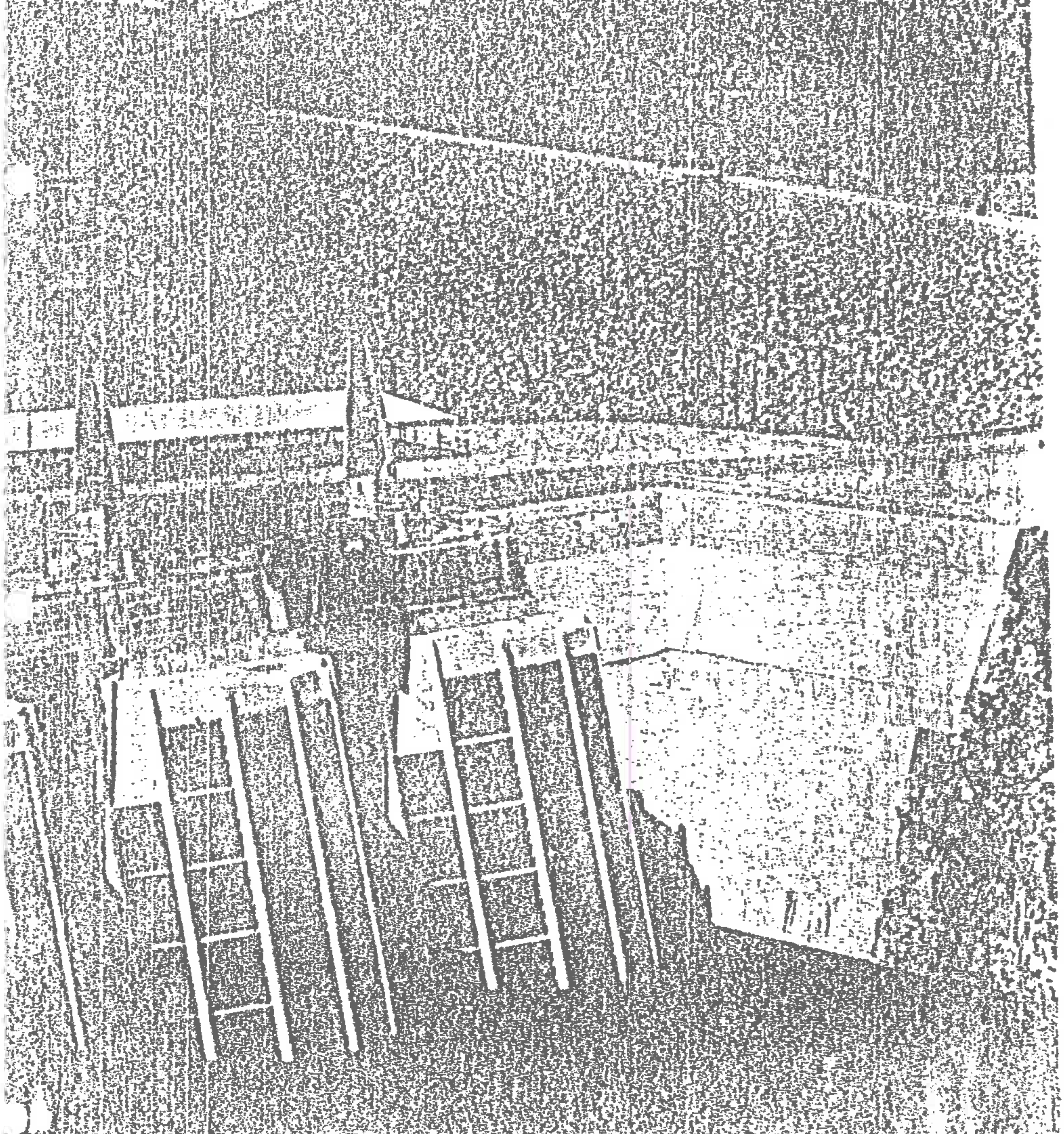
KIRJALLISUUTTA KÄYTÖSSÄ OLEVISTA KALATEISTÄ JA NIIDEN TOIMINTAAN LIITTYVISTÄ ONGELMISTA

FISHWAYS

INTERNATIONAL JOURNAL FOR HYDROELECTRIC DEVELOPMEN

Water Power

JUNE 1973



Special Issue

Stream biology and hydroelectric power

By G. J. Eicher*

The author describes the many ways of allowing fish to pass by or through dams, both in the upstream and downstream directions. He explains why some are more successful than others and also mentions other positive and negative effects of dams on fish life

FOR MANY YEARS, builders of large dams on rivers supporting migrating fish have been coping in varying degrees with the problems of maintaining fish populations by passing fish, or failing this, substituting other means. In early years, means were provided only for upstream migrants, and those moving down were normally faced with a dead-end at the dam or forced to go through the turbines.

With the increasing interest in, and value placed upon, living resources such as fish runs, few stones are now left unturned in ensuring fish the best routes possible, both up and down river past a dam.

Fish encountered in dam building fall roughly into three classes: resident species which undergo intra-river migrations, anadromous types (developing in the ocean and ascending rivers to spawn), and catadromous—those developing in fresh water and returning to the ocean to spawn.

The most commonly-found group, and that accounting for the vast majority of problems at dams, is the anadromous sector. Specifically most of the species in this group are salmon and sea-run trout.

Upstream passage—the collection system

Those in the business of designing fishways frequently receive plans for fish facilities from neophytes who are intrigued by the problem as they understand it and who have developed plans for passing fish with what they consider to be novel and fool-proof methods. Universally, they ignore the principal and most difficult part of fish passage—the collection system.

It is unfortunate and frequently pathetic that these people do not undertake the elementary step of determining the nature of the problem before expending large amounts of time and money to attack an area in no need of new solutions with approaches that others before them have developed and discarded many times over.

Amazingly intricate, and sometimes prohibitively costly, schemes involving variations of locks, tramways, buckets, tubes and syphons have been detailed in this way, all with the assumption that the fish somehow magically appear at the lower end ready to be transported.

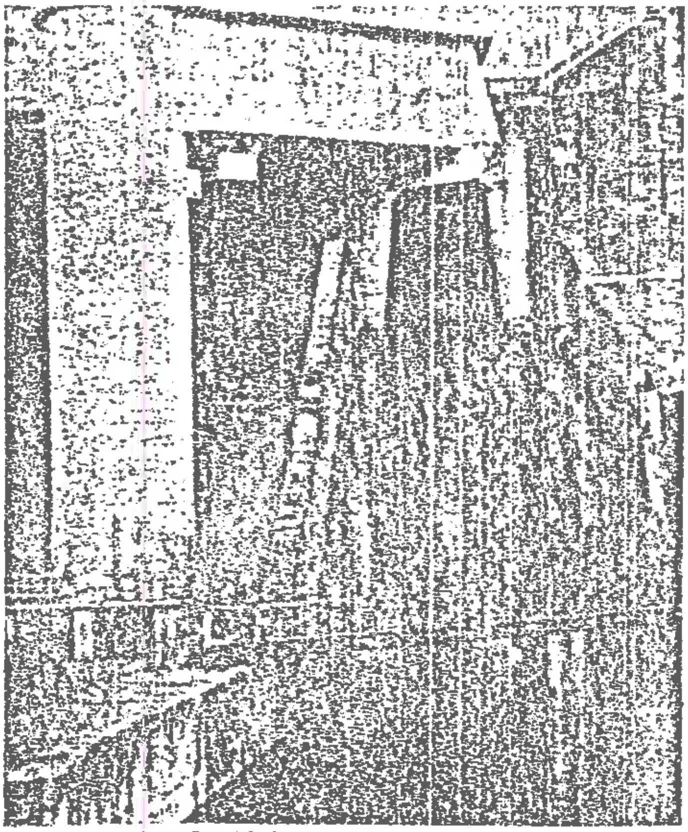
In actuality, the reverse of this assumption prevails. Efficient, proven and relatively-inexpensive systems of moving fish over dams have been developed over the years in many forms, as we shall see later. Their application and design may vary, but are not too critical from dam to dam.

The most exacting part of fish passage is getting the beasts to enter the lower end. This involves exhaustive planning, precise evaluation of all factors with respect to topography, hydraulics, physical features of dam, powerhouse, spillway and tailrace, and frequently modelling of all these.

Even then, the selected prototype collection system must usually undergo extensive alteration and tinkering after operation commences, in order to have the fish accept it. In this area, experience on the part of the designers is essential.

Design of the collection system must accommodate the habits of fish to swim upstream as influenced by flows of water issuing from the hydro plant. In normal circumstances, this translates into entrances to the system from both sides of a spillway if frequent spilling is expected, one side if spill is only occasional and of short duration, and disregarded if the frequency is minor, such as less than once a year.

Powerhouse collection schemes may be quite varied, depending on such factors as size of powerhouse, depth of draft tubes, species of fish, river size and many lesser



A vertical Borland fish lift for Atlantic salmon and elvers at Ardnacrushna dam on the River Shannon, Ireland

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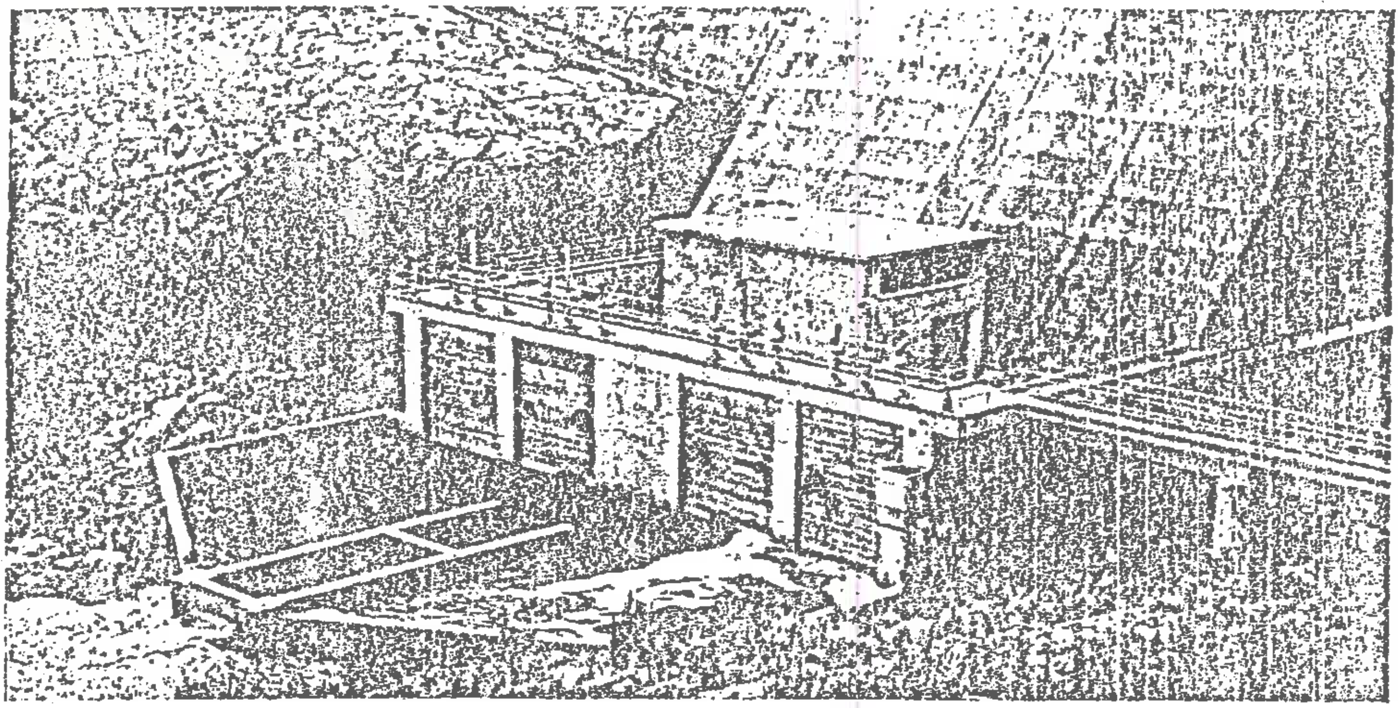


The intake of a four-unit Borland lift at Orrin. The concrete skeleton downstream of the lift houses an electronic counter for enumerating the fish

items. The placement should ensure that almost every fish will find an entrance within a reasonable period of time such that its migration pattern will not be disturbed.

The basic aim of the system is to take advantage of all flows of water in the area downstream of the dam so that a fish following any flow will eventually be led into a fishway. This seemingly simple premise is often difficult to achieve at moderate cost.

It means that confusing or false attractions leading fish into dead ends must be eliminated or overcome by stronger flows from the right directions. The eventual entrances must be in the *most upstream positions possible.*

Every portion of the tailrace area must be either reached by a flow from a fishway or covered by a current so powerful that fish must avoid it and divert into the fishway pattern.

The spillway's flow presents such a velocity barrier, shunting fish to either side where a fishway entrance flow will pick them up. It is frequently difficult to provide transverse flows from fishways which will be felt all of the distance across powerhouse discharge areas.

This situation prevails on most of the large multi-turbined dams on the Columbia River in the USA, and to counter this, auxiliary collection systems with individual entrances over each draft tube are provided. Normally these are not as effective as the larger main entrances at each end of the powerhouse; however they probably collect many individual fish otherwise lost to confusion in between.

At the Wells "hydrocombine" dam on the Columbia wherein spillway and powerhouse are combined and draft tubes deeply submerged, transverse flows above the draft tubes are produced and augmented by large jet flows.

The currents produced are sufficient to meet in the middle of the structure. No powerhouse collection system other than the large entrance gates at either end is provided.

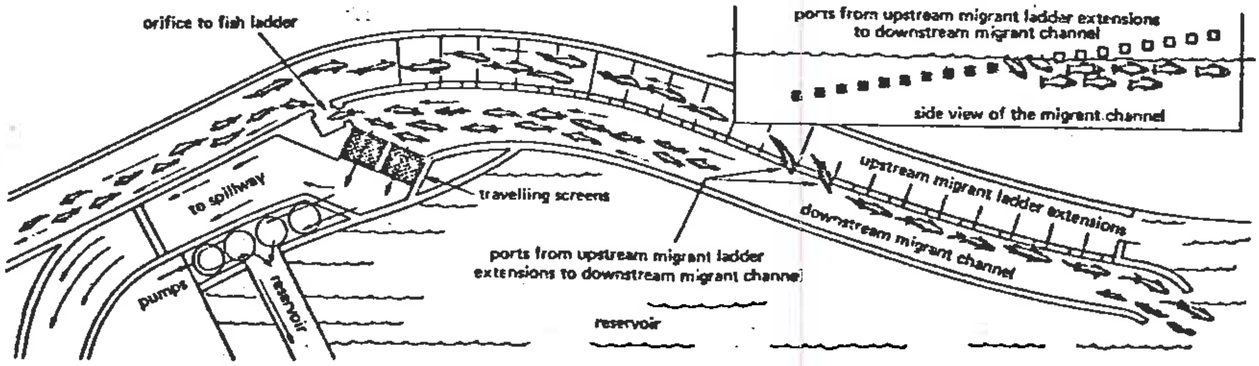
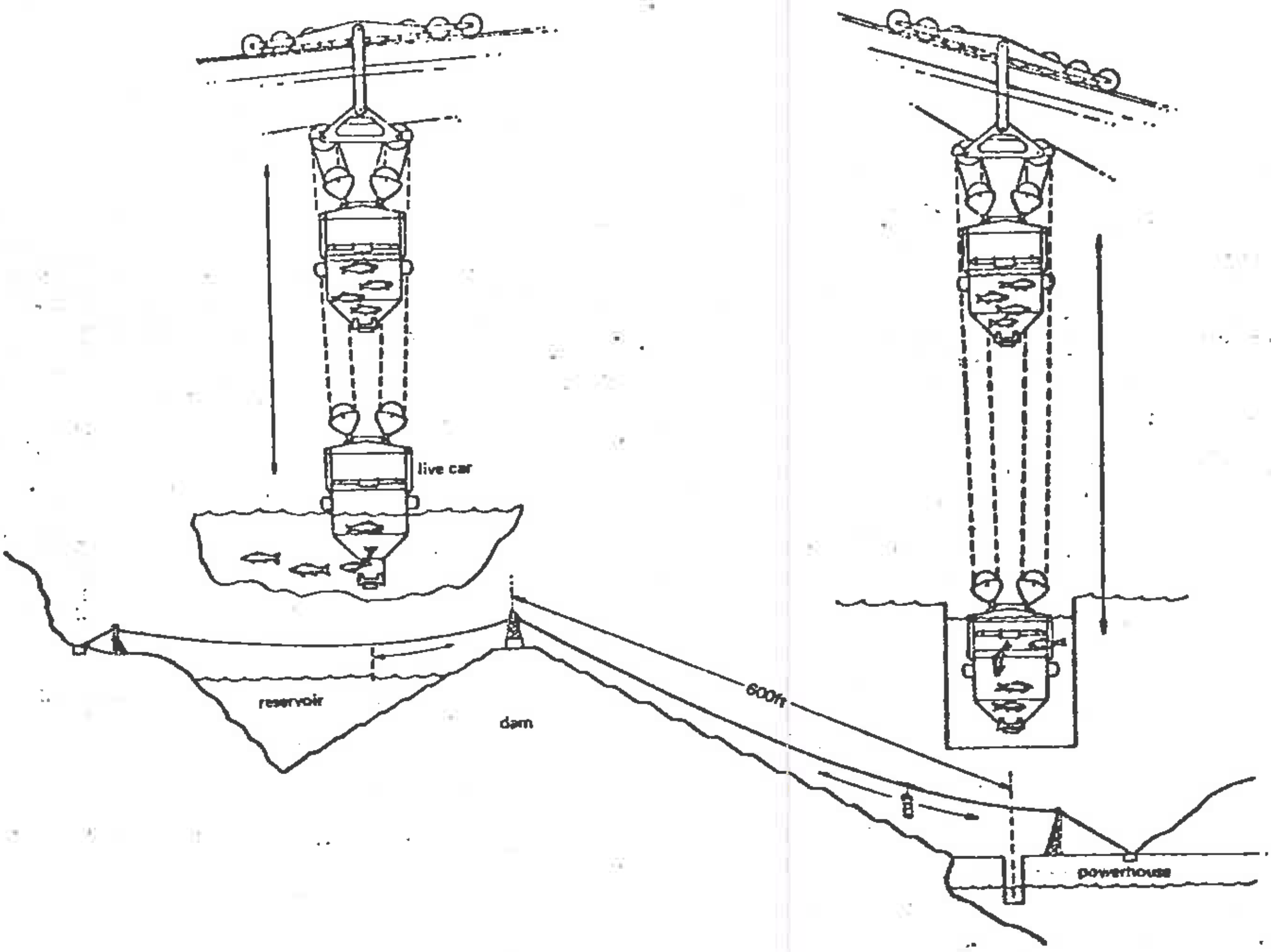
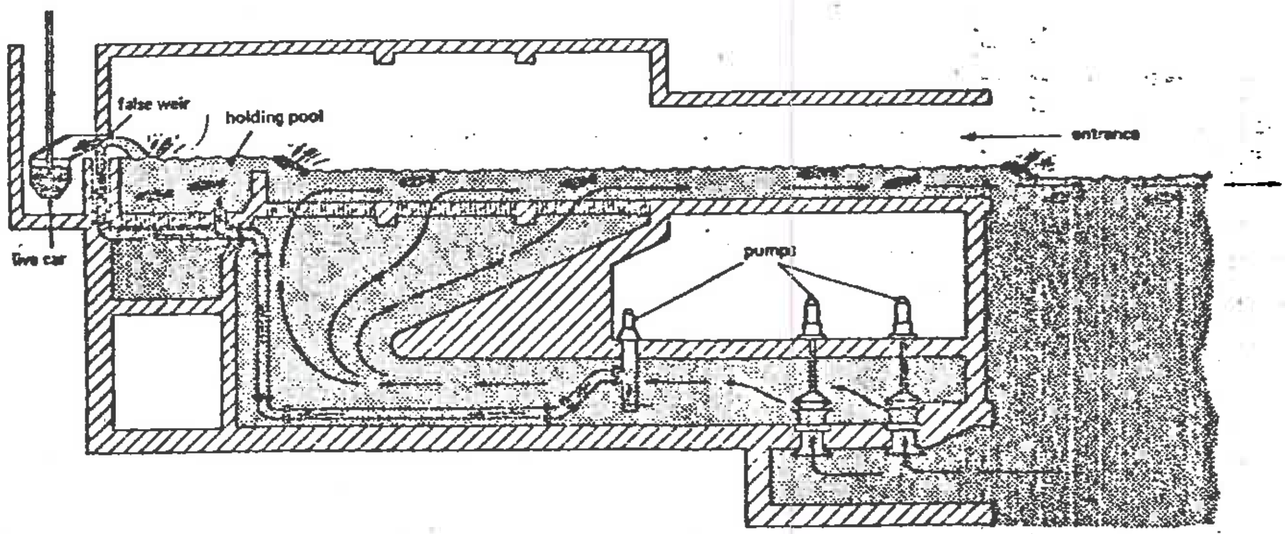


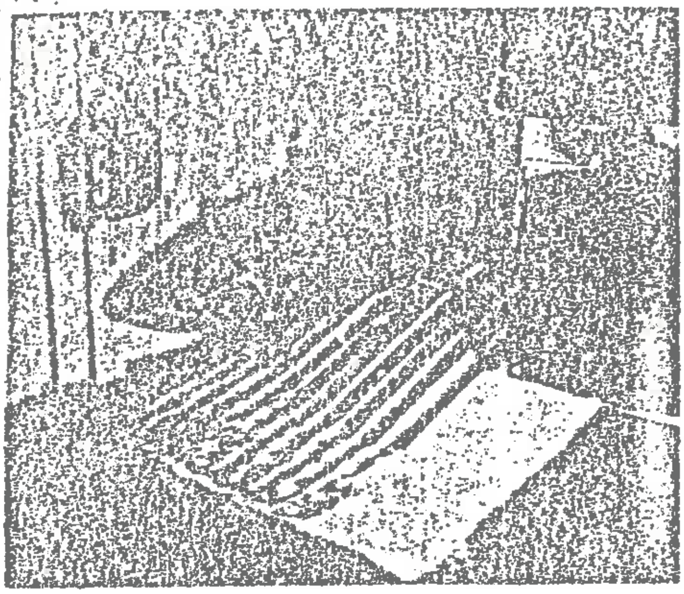
Diagram of the arrangement for handling upstream and downstream migrant fish at the North Fork project, Oregon



Operation of a fish trolley over a 400ft-high dam in Oregon



A powerhouse collection system bringing fish to the live car of a fish trolley



Male steelhead trout passing over a false weir and breaking a photo-electric circuit causing tabulation on a counter

Auxiliary flows

Since the quantities of water used in the fishways are small in relation to the total tailrace flows, if these alone were used in the proliferation of entrances and transportation channels at a large dam, the movement of water would be too slight to be felt by the fish. Thus, augmentation by auxiliary water is required, either by gravity from the forebay or by pump from the tailrace.

This water is introduced through gratings, usually with one-inch spaced bars on the bottom or sides of entrance chambers at velocities somewhat less than one foot per second.

Actual quantities employed are arbitrary, but governed by river size, powerhouse size and configuration, spill characteristics, etc. Most of the Columbia River dam fishways discharge 1000 to 2000cusecs, and transportation channels and flows are sized to provide velocities of about 2ft/s, a velocity seemingly acceptable to most species of fish.

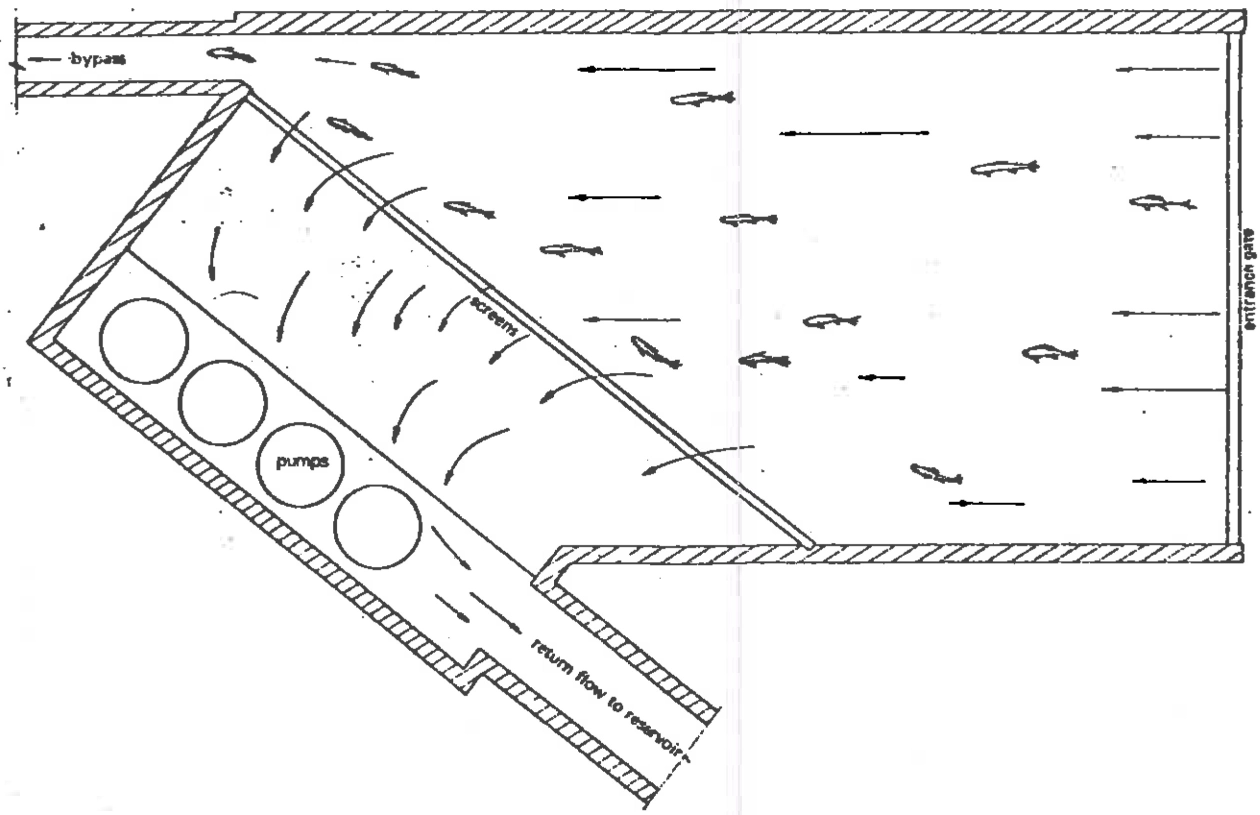
After assembling fish in the collection system, they may be then taken over the dam by a variety of means including atmospheric or pressure locks, tramways, trap-and-truck, and a wide choice of ladders including overfall, orifice, vertical slot, or a combination of these and Denil types.

A favourite system in Scotland, Wales and Ireland is the Borland lift, an atmospheric lock consisting of a long concrete tube slanting from tailrace to forebay. After a certain number of fish enter, a gate closes at the bottom, and it gradually fills by water running down the slope which is followed by the fish until the rising water permits them to emerge above the dam.

Trap-and-truck operations provide an economical means of transportation of fish over any height of dam. This system has been developed to a state ensuring trouble-free effective passage if conscientiously operated, but it is susceptible to slip-shod operation, if not well supervised. It is popular in northwest USA.

Similar in concept is the tramway, wherein a tank containing trapped fish, instead of emptying into a truck, moves on rails or trolley over the dam and releases its load into the forebay.

In a pressure lock, fish go from the collection system into a chamber inside a lower level of the dam, a gate closes tightly in back of them and water is allowed to



Plan view of the North Fork type o artificial outlet, showing the principle of operation

...ter the system from the forebay. When the pressures equalize, a gate in the face of the dam opens, allowing the fish to emerge into the pool at a considerable depth.

Only one of these has been constructed: at the McNary dam on the Columbia River. Because other fishways proved satisfactory, it was unfortunately never used or evaluated. A similar lock was proposed for the Nez Perce dam on the Snake River, which was never built.

Ladders come in an infinite variety of styles and configurations. Most popular is the overfall, in which the water cascades over a weir into a pool of length and depth calculated to turn the flow back on itself and thus kill the energy.

The same result can be accomplished by putting the water through an undershot orifice at the bottom of the pool, although this is less successful with most fish. Many systems use a combination of overfall and orifice.

Head on the weirs is almost universally one foot in North America and 50% greater in Europe. Both seem to work well, with the higher head more economical because fewer pools are required for the same total lift.

One problem with overfall ladders is a side-to-side oscillation at certain flow levels which inhibits fish movement and may even damage the structure, but this may be controlled by reducing the ratio of overfall-crest size to pool width.

Vertical slot ladders come in a variety of configurations, but all rely on the flow through the slot being directed into the pool below so that it turns back on itself, dissipating energy. This type has the advantage of being functional through a wide range of flows and depths, although it tends to use more water than an overfall.

The Denil fishway consists of a relatively-narrow channel with internal fins extending about 6in into the structure from around the sides and bottom, spaced from 6in to 2ft apart. These fins redirect the flow back on itself, thus dissipating the energy and resulting in a turbulent area in the middle of the trough having almost zero velocity.

Fish are able to swim through this with ease and accept the type of fishway well. Its greatest advantage is its steepness (up to 1:4 slope), and this, combined with inherent narrowness, results in a relatively small structure.

It does tend to use more water than an overflow ladder, but this type is quite popular for Atlantic salmon and alewive passage in Maine, USA, and an aluminium version—prefabricated in 10ft sections for air transport—is used extensively at natural barriers in Alaska.

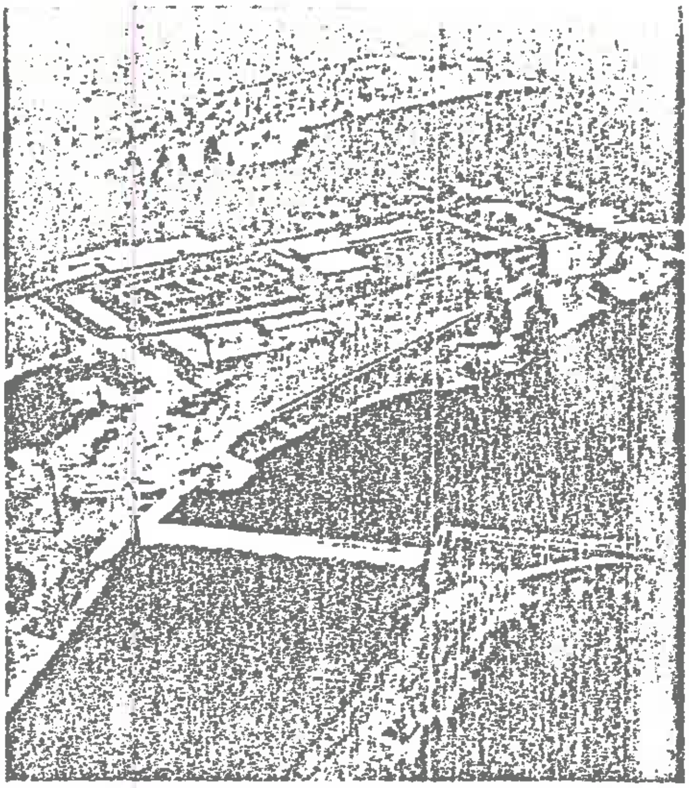
Passage through tubes

From time to time the question arises as to the possibility of passing fish through pipes or tubes. With downstream migrants, this is no problem: travelling with the flow, once introduced to the tube they have little choice but to pass on through.

At the Portland General Electric Co North Fork project on the Clackamas River in Oregon, USA, downstream-migrant salmon have been by-passed around three dams at once by a 5 mile-long, 20in-diameter pipe since 1959. Scientific evaluation has judged the method successful.

Upstream passage by this method has long been fraught with unknowns. The Bonneville Fishway Laboratory on the Columbia River, however, has recorded successful upstream migration through endless pipes by chinook and coho salmon for distances of several hundred yards. Passage through unlighted fishways has also been deemed successful.

After upstream-migrant fish surmount a ladder, a problem develops with respect to getting them out of the facility into the forebay, which ordinarily fluctuates from a few to several feet in elevation.



Large hatchery on the Cowlitz River, Washington, accommodating eggs from 30 000 adult fish. The barrier dam in the foreground diverts fish into the ladder leading them to the hatchery

A number of methods, most of which involve varying degrees of mechanization are available, and each has its own array of problems.

The most common one is orifice control, in which water-flow through the topmost series of weirs is through bottom orifices only. This permits a flow through a wide range of forebay levels, but also one varying with the head.

To counteract this and ensure a constant quantity downstream of this section, auxiliary water is introduced, usually through a bottom grating and an automatically-adjusted gate valve.

The method is limited by the proclivity of fish to sound to reach the bottom orifices, and all species must be accommodated, since unwanted ones will clog the system if they cannot pass through. About 7ft of fluctuation is the maximum accommodated by this method.

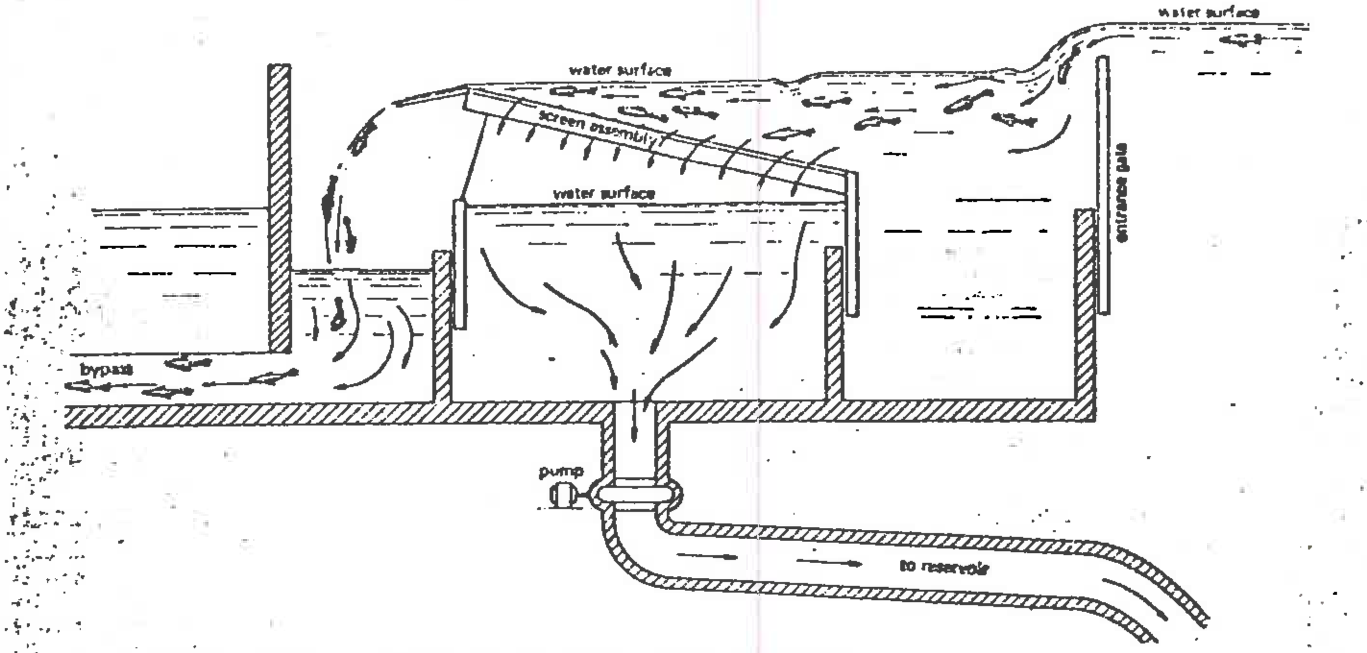
Another system involves slanting, sloping or telescoping the topmost series of weirs by means of automatic controls. This can theoretically accommodate wide fluctuation, but cost limits actual ranges.

Designing the topmost series of pools to flow out into an adjacent channel through side ports automatically controlled to synchronize gates with forebay level, permits a wide range of fluctuation, and the greatest known swing of 19ft at the North Fork project in Oregon uses this method.

All of the foregoing solutions require automatic controls of some sort, and these offer problems of their own.

The Harza Engineering Co has developed an exit system for a large dam in Argentina in which a complex of vertical slot weirs, coupled with grated chimney overflows, accommodates a wide range of forebay levels and fish species without automatic controls of any kind.

Because of species rejection of orifices, at some Columbia River dams these sections are being replaced by combinations of vertical slots and automatic controls.



Longitudinal view of a Pelton artificial outlet, showing the principle of operation

Passage through reservoirs

After fish have successfully negotiated a fishway and are in the forebay, the problem arises of their finding their way through the reservoir and into the correct stream (that which would normally have been their destination had the hydro scheme not been in existence).

For upstream migrants this does not appear to be a problem. Extensive research in the Columbia River system and elsewhere using tagged fish and following individuals carrying sonic devices has shown that, for the most part, no difficulty is experienced in successfully reaching the proper destination.

The same cannot be said so universally for downstream migrants. At certain reservoirs situated in habitats marginal for salmonids, the reservoir has proven a serious deterrent to juvenile fish on their way downstream.

This is particularly true in cases of rather long deep reservoirs which tend to stratify, particularly if in warm climates.

Another complication may be reservoir inflows of different temperatures causing layering. This presents fish with the difficulty of following a particular waterpath they identify as from their parent stream but which is supplanted by a larger, and perhaps colder, flow which dominates the course into the turbines.

By tending to remain in their familiar water, they sometimes never find their way out.

Accommodation of upstream movement of adult fish is the least difficult area of fish protection at dams. Provision of successful avenues of passage past a hydro project for developing young and spent adults of some species is a frustrating and frequently unsatisfactory effort.

Millions of dollars have been spent in development effort and research on downstream migrant fish passage

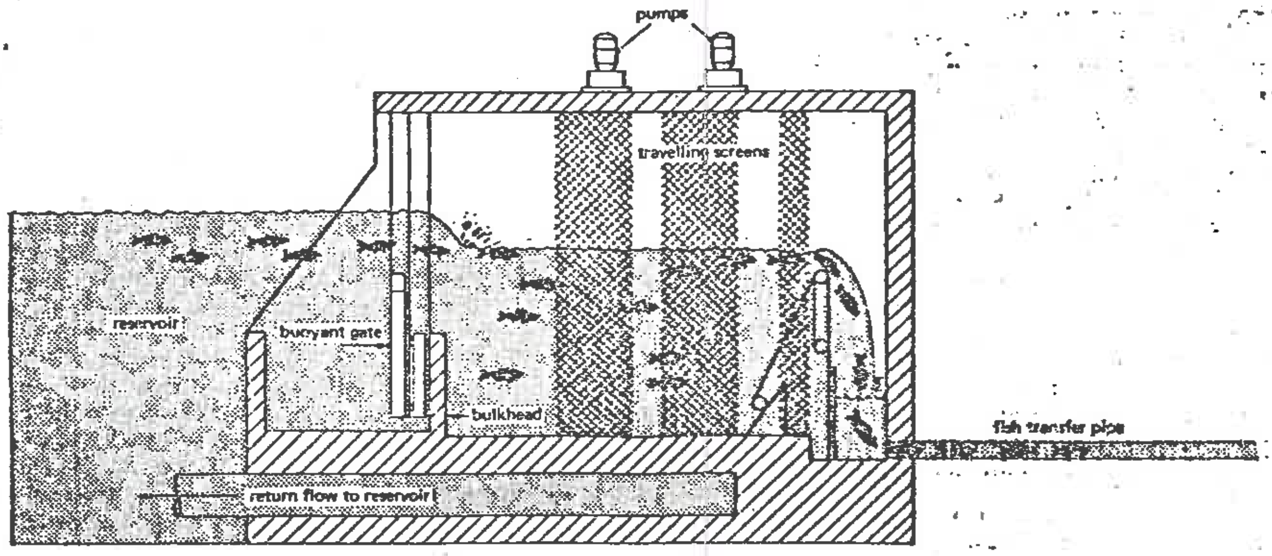
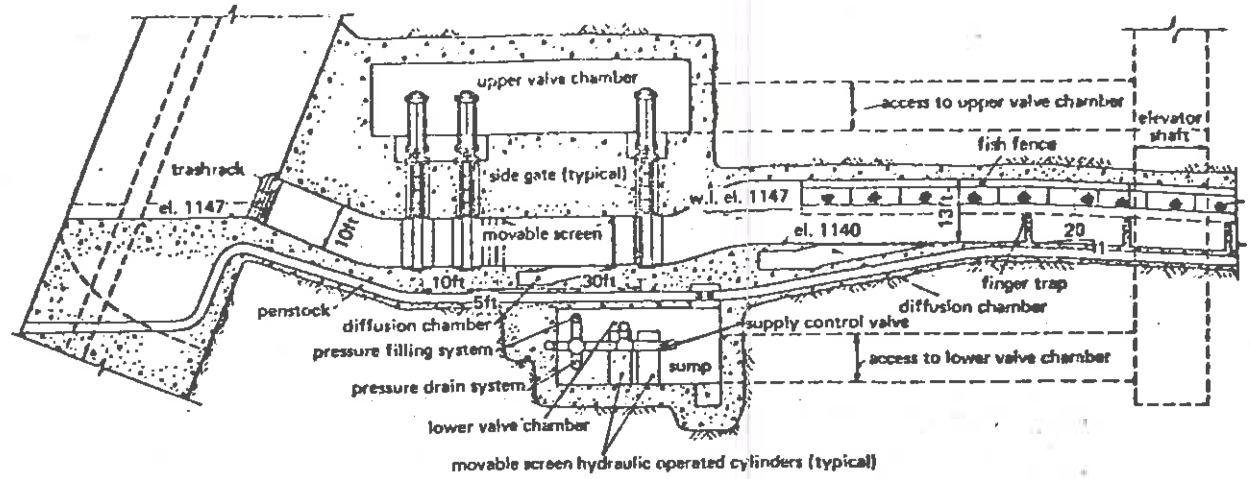


Diagram of the round Butte type of artificial outlet



Profile of a pressure fish lock in which fish enter at the right from a section of the fish ladder.

without overwhelming success. In general, two main approaches are employed—allowing the fish to go directly through the turbines or providing a by-pass route.

Passage through the turbines is not necessarily as damaging as it would appear, and design and arrangement of the blades can have profound effects on fish mortality. Fortunately, in this case what is good for fish is also best for power production.

Specifically, elimination of cavitation and best efficiency of operation, both desirable operating conditions, result in lowest fish mortality—as also does slow blade-tip speed.

This is usually accomplished by locating the centreline of the turbine runner as low as possible in relation to the tailwater, eliminating tight passages and protrusions, which are damaging, and operating at the most efficient gate openings.

Observance of these conditions has resulted in survivals of over 80% at heads of more than 400ft.

Head in itself is of only minor importance in turbine mortality, and in contrast to this figure, survivals of less than 20% have been found at installations with less than 40ft of head.

It was once thought that Francis turbines were more damaging than Kaplan types; however, experiments have produced little difference under comparable conditions.

By-pass systems of downstream passage normally involve some method of discouraging penstock entry with diversion into the by-pass. In Scotland and Ireland, coarse screening of the turbine intakes is combined with the provision of routes through Borland lifts.

In the northwest US and Canada, location of penstocks at the deepest levels of reservoirs discourages sounding of fish and encourages them to use alternate surface routes. A fairly successful method is the artificial outlet in which a flow of 100-400cusecs is induced from the reservoir.

After a short distance, the fish are separated by screens from the bulk of the flow, which is then pumped back into the reservoir for power use. A small quantity of water takes the fish into the tailwater, a ladder, or a trap for mechanical transport.

Artificial outlets use two types of screen. In one, the water flows over an inclined humpback screen at fairly high velocity—most of it falls through the screen, with a small quantity carrying the fish over the lip into a by-pass—in the other, vertical travelling screens are set in a line at an angle of about 30° to the flow.

Most of the water passes through the screens with only a small quantity carrying the fish on into the by-pass.

Diversion of downstream migrants

Through the 1950's, much research was carried out on methods of diverting downstream migrants away from the power intakes at dams.

Parenthetically, similar research is now plowing the same ground in an attempt to devise methods of preventing fish from moving with the water flow into the intake structures at thermal power plants. Unfortunately, this is largely being pursued in ignorance of the millions of dollars spent on earlier research exploring practically identical problems.

Also unfortunate is the fact that the greater part of these funds was spent fruitlessly. The only truly successful systems have involved some form of screen—fixed, travelling, drum or otherwise.

Next in success has been the louvre, which is a line of slats set at an angle of about 20° to the current, which tends to shunt the fish past the slats, and into a by-pass. Fairly fast approach velocities (3-5ft/s) are necessary at fairly constant levels, which limits the use for turbine intakes.

The effectiveness has been quite variable.

Intriguing to many power producers has been the idea of diverting fish by electric-field barriers. Unfortunately several million dollars spent on research in this area over a period of several years have not brought success.

While fairly simple electric fields do a good job of stopping upstream migrants, the most expensive and sophisticated square-wave DC systems have proven useless in diverting fish moving with a water flow.

In some experiments, lines of electrically-charged chains dangling in water seemed to prove effective. They also proved as effective without electricity.

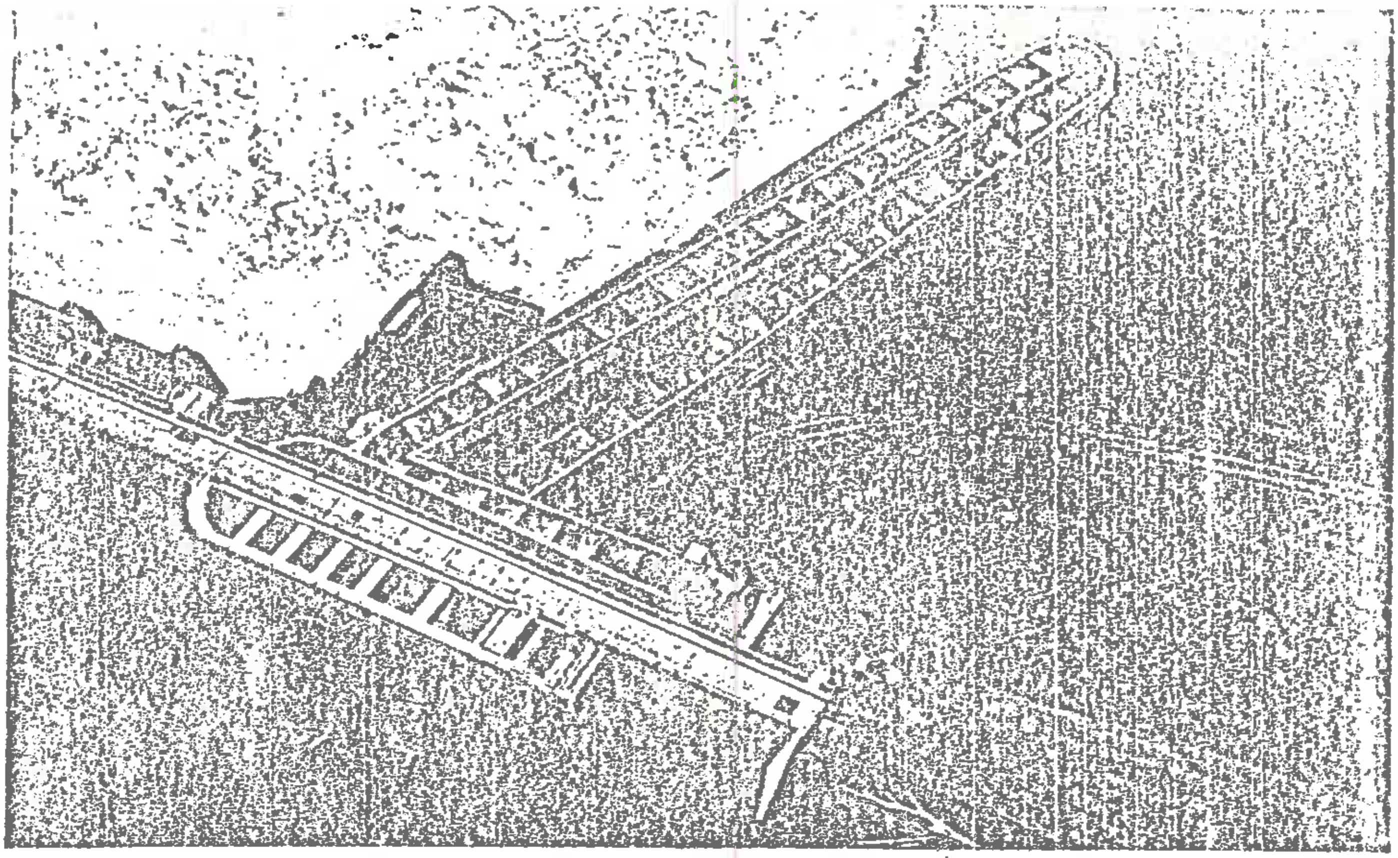
Unfortunately, neither system was good enough.

Somewhat smaller, but still substantial sums have financed research into guidance using light. Both bright and exceedingly-dim sources were tried, and the results have been the same.

Another area intriguing to many is the use of streams of air bubbles. Experiments with countless variations of this have all been characterized by the same lack of success.

Approximately the same relative effort has gone into the use of sound for guidance, and with similar results.

Fish do perceive sound, but its effect is slight and of short duration either as an attraction or repellent.



Spillway fish ladder at the Priest Rapids development on the Columbia River. The section above the dam provides orifice control of forebay fluctuations

The key to successful diversion by screening is the by-pass. Merely stopping fish is not enough. They must have some other place to go or they eventually impinge on the screens and die. A good by-pass system requires a flow along and past the screens that is somewhat stronger than that into them.

Minimum flows

In hydro schemes involving a diversion dam shunting flow through a flume or pipe to a powerhouse downstream, the area between the dam and powerhouse must have sufficient flow to keep fish alive and performing their normal functions.

These will vary considerably with fish species, but must in all cases be sufficient to maintain proper temperatures, oxygen levels, depth for transportation or spawning, and sufficient cover to protect from predators.

A different problem which has been around for years but has only recently been identified, is that of super-saturation of dissolved gases (mainly nitrogen). Water plunging over spillways entrains air and is subjected to the pressure of deep spilling basins causing it to form finely-divided bubbles which enter into solution. The same effect occurs below natural waterfalls.

Fish affected by this have bubbles under the skin in the roof of the mouth, at the base of the fins and elsewhere. Small fish may completely fill with gas and explode. In other cases, embolism causing death is the ultimate result.

Avoidance of spill through flow manipulation or designing spillways to prevent deep plunge are desirable.

Frequently when fish passage is not possible it may be practicable to maintain populations of migratory fish confronting dams by means of artificial hatching and rearing.

Some very large hatcheries for salmon have been built in the northwest USA for this purpose, notable examples being the Dworshak hatchery on the Snake River and the Cowlitz hatchery on the Cowlitz. Each is capable of caring for runs of several thousand adult fish.

Popular in British Columbia, Canada, is the artificial spawning channel. In these, a channel embodying the best characteristics for spawning and hatching in gravels and water is prepared, and fish are allowed to spawn in them naturally. These have proven variously successful.

Some have also been built in conjunction with major hydro projects on the Columbia River.

Summary

While hydro projects and fish are not always compatible, it is frequently possible to provide for continuance of healthy runs through proper design of dams and facilities to protect fish.

Unquestionably, many hydro projects have enhanced runs of migratory fish downstream of the dams and others have provided abundant fisheries in the impoundments far greater than would have been possible in the free-flowing streams.

Areas in which dams can benefit rivers downstream include: stabilization of flows away from meagre insufficient minimums and savage damaging floods; stabilization of temperatures, preventing lows which inhibit growth for many months of the year and highs which cause disease; oxygen depletion and direct mortality; enhanced food production through concentration of nutrients and transformation into food organisms in the reservoir; and reduction of siltation and bed-load movement, both of which can severely limit spawning success.

Examples of these are numerous. One of the most outstanding is the enhancement of chinook salmon production in the Sacramento River in California, USA, as a result of all of the above-listed factors accruing from the Shasta dam.

Pumping saves water and power in fish-passage facilities

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Pumped water to attract fish to upstream passageways is saving valuable energy water at Pacific Northwest dams. The pumping equipment at these facilities is both tremendous in size and unique in design. At Ice Harbor Dam for example, 3,150 cfs of pumping capacity is installed, and 7,500 cfs at McNary Dam; each would make quite a substantial river. It is far more economical to pump the quantities of low-head attraction water from the tailwater pool than to divert high-head water from the power turbines.

The Columbia River and its tributaries constitute by far the largest hydro-power stream system in the United States, with a potential power capacity of 34,000,000 kw. The 1985 estimate of power consumption for this area is 23,000,000 kw, of which about 95 percent will be hydroelectric. The comprehensive development of the Columbia River and its tributaries—notably the Snake River—by private utilities, the U.S. Army Corps of Engineers, and the U.S. Bureau of Reclamation will require the construction of a considerable number of dams.

One of the most mysterious phenomena of nature is the periodic migration of anadromous fish. Species such as the salmon must be able to reach the spawning ground where they were hatched, and their fingerling offspring must be able to make the return downstream trip with a minimum of difficulty. Whenever a barrier to free passage of fish is placed across a watercourse, this natural process is prevented.

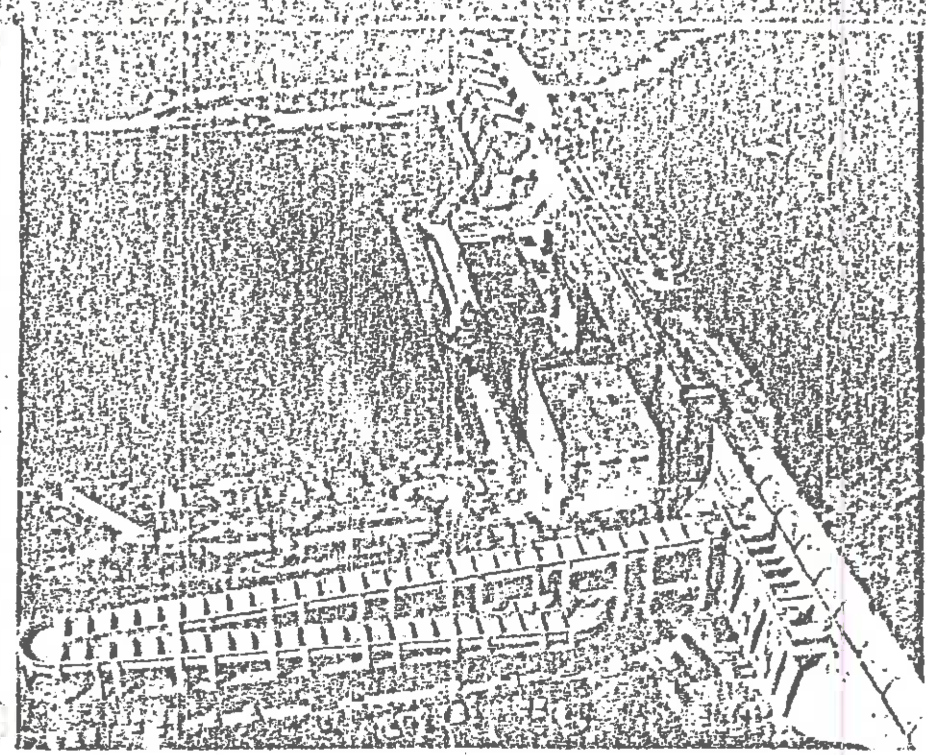
The harvest of salmon and steelhead from the Columbia River has been estimated at $20,000,000 annually. There is also recreation for the sports fisherman, the value of which cannot be estimated. The cost of including fish facilities averages a staggering $10,000,000 per dam, but the results more than justify the expenditure. A survey showed that, in one 16-hour period, 21,000 Chinook salmon passed through the fish facilities at McNary Dam. Chinook, the most numerous migrating fish on the Columbia, account for about 30 percent of the total number of fish that utilize the facilities. Considerable research is being done on artificial spawning areas, with promising results. To date however, successful spawning requires that the natural migratory process be followed. While passing upstream, the fish must not be injured, overexerted or unduly delayed.

It is evident that the fish cannot fight their way upstream through the tailwater of power turbines or through the spill water of a high dam. How then can they pass this barrier? There are several methods of transporting fish from the tailwater pool, past the dam, to the backwater. One way is to transport them in hoppers on mechanical tramways. Another is to install a fish lock similar to a navigation lock. The most widely used method is the fish ladder. No matter what transportation system is used, a successful method for attracting the fish is necessary. The sports fisherman with his lure is not alone in his efforts to attract fish.

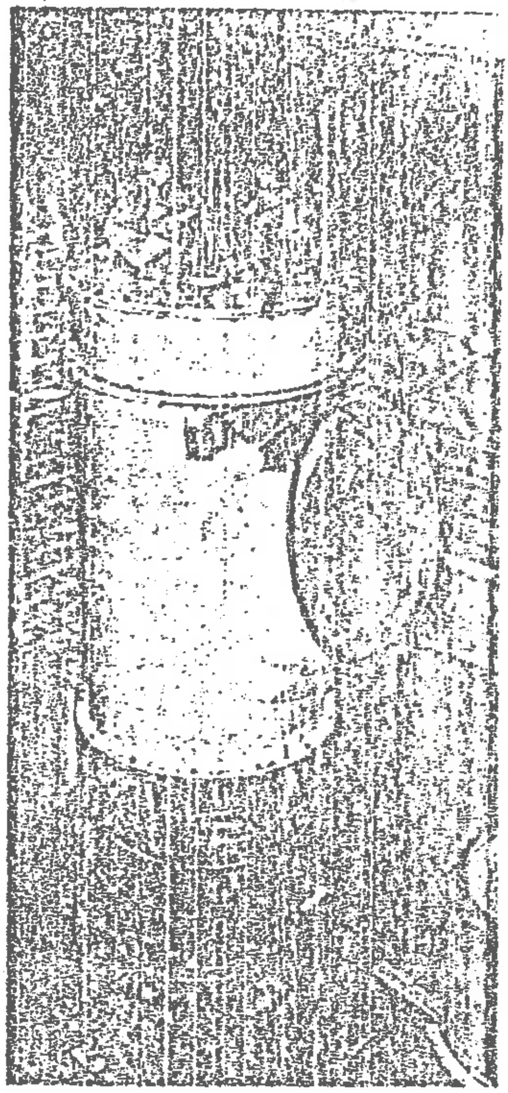
A fish ladder consists of a water-filled passage or a series of connected pools through which the fish swim up past the dam. Each pool has a 1-ft gain in elevation over the preceding one and is separated from it by a weir with a submerged orifice. The fish swim through this orifice to the next higher pool. Water flows from the backwater storage down the ladder to the tailwater pool below the dam. See Fig. 1. There are usually two fish ladders in each installation, one on each shore of the river. Within the fish passage, such conditions as flow, velocity and direction, water noises, and lighting must all duplicate those familiar to the fish. On the downstream trip the fingerlings usually pass through the power turbine, over the spillway, or through the trash flume. Under some conditions, however, special facilities for the downstream passage are also required.

Attraction water

Since research has shown that fish follow the shoreline, fish entrances at the center of the dam are not necessary. It has also been found that an entrance 6 ft below the surface of the tailwater pool attracts fish more efficiently than one that is deeper or closer to the surface. The most critical condition to be maintained at the fish entrances has been found to be a velocity against which the fish will naturally swim. Experiment has shown that each entrance must emit about 60 cfs of attraction water at a velocity between 4 and 8 fps. The velocity in the transportation channel must be main-



The fishway is a necessary bit of difficult construction at dams in the Northwest. Pumped water attracts salom to this fishway (in foreground) at Ice Harbor Dam.



Pump for fish attraction water lifts 308 cfs (193 mgd) against a 5-ft head.

tained at 2 fps. Provisions are usually made to adjust the flow so that the best results can be otained through field investigation under various hydraulic conditions.

Water flowing down a fish ladder from behind a dam is of insufficient quantity to produce the required flow conditions at the entrances and in the transportation channel. To allow additional water to flow from behind the dam for this purpose is not economical considering the amount of generated power that would be lost.

Pumps are therefore used to create attraction-water flow. These pumps take their suction directly from the tailwater pool and discharge into the collection channel. See Fig. 1. The attraction water flows through the collection channel, out through the fish entrances, and back into tailwater. The pumps never actually pump the fish; they swim against the attraction flow, through the entrances into the collection channel and then on to the fish ladder. They then swim from pool to pool of the ladder, gaining one foot of elevation at each pool, until they have reached the elevation of the backwater, where they are free to continue their upstream migration.

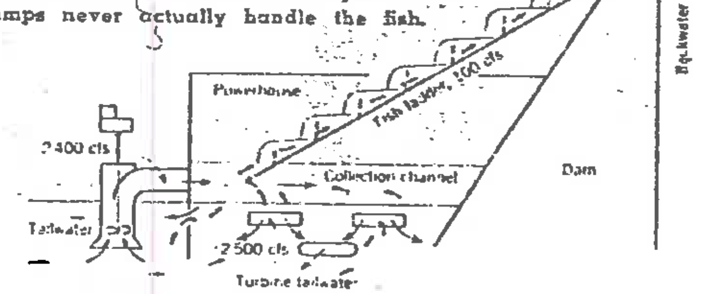
Total quantities of attraction water vary between installations. McNary Dam, for instance, requires a maximum capacity of 7,500 cfs through three pumps installed on the powerhouse side of the dam. The Ice Harbor installation will have a total capacity of 2,400 cfs installed on the powerhouse side of the dam and 750 cfs on the North Shore. These tremendous quantities of water at pool-to-pool heads ranging below 10 ft present a considerable pumping problem. Vertical wet-pit propeller pumps have proved best suited to meet these hydraulic requirements. In addition their physical configuration makes them well adapted to the limited space available in the pump structure. See Fig. 2.

In line with the impressive size of the generating equipment in the powerhouse, fish attraction facilities are among the largest continuous-duty pumping installations. The pumps at McNary, for instance, have impellers 20 ft in diameter and are driven by 2,800-hp motors.

Ice Harbor Lock and Dam

The Ice Harbor Lock and Dam project of the U.S. Army Corps of Engineers, scheduled for completion in 1961, is the first of four authorized dams on the lower Snake River that will extend slack-water navigation

FIG. 1. Schematic diagram shows Ice Harbor fish facilities. The fish swim against the pumped attraction-water flow into the entrance orifices, to the ladder proper. They then swim against the ladder flow and up to the backwater pool, where they are free to continue their upstream migration. The pumps never actually handle the fish.



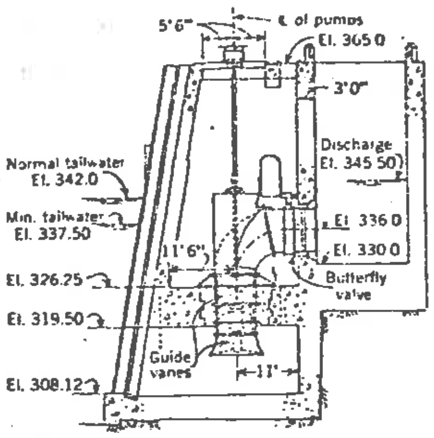


FIG. 2. At pump installation for fish attraction at Ice Harbor, suction pit opens directly into tailwater pool. The pump can be pulled out of the embedded case. This design allows complete maintenance from above rather than from below through the suction pit.

from the confluence of the Snake and Columbia Rivers 140 miles upstream to Lewiston, Idaho. The Lower Monumental, Little Goose and Lower Granite dams will complete this project, allowing slack-water navigation up the Columbia and Snake Rivers some 465 miles from tidewater. An annual traffic of 2,500,000 tons is expected to pass through the lock at Ice Harbor. The ultimate hydroelectric generating capacity will be 540,000 kw through six turbine generators.

The Ice Harbor Dam will have two separate fish ladders, one on each shore. Because of the attraction exerted by the turbine tailwater, the south shore or powerhouse side of the dam will have the larger fish facilities. These consist of entrances from the tailwater pool, transportation channels, the ladder proper, and the pump station. Of course, these basic components include an unbelievable number of control devices, supply conduits, and diffusion chambers as well as a fish counting station.

The south shore at Ice Harbor will have three entrance locations. The first is in the non-overflow part of the dam between the spillway and the powerhouse. The second, running across the base of the powerhouse, consists of twelve submerged orifices, each 8 ft by 1½ ft, two for each turbine tailrace. The third is made up of two 12-ft overflow weirs placed at the south end of the tailrace.

All three of these entrances come together at the collection and junction pool. Here, pumped attraction and transportation water is introduced to support the required flow conditions through the collection channel and out the fish entrances. The junction pool leads directly into the lower end of the fish ladder. To maintain proper attraction conditions at the entrances under maximum tailwater levels, the following amounts of attraction water are required:

Non-overflow entrance	1,000 cfs
12 powerhouse entrances	720
South entrance	780
Total	2,500 cfs

The fish-ladder flow from behind the dam is only 100 cfs; therefore a maximum pumping capacity of 2,400 cfs of attraction water is required. In order to meet varying capacity requirements under different pool elevations, pumps of 300-cfs constant capacity were selected. Eight units give a 300 to 2,400-cfs range in 300-cfs increments at a pool-to-pool head of 4 to 5 ft. Worthington Corporation furnished the eight vertical-propeller pumps with discharge connections 8 ft in diameter. The suction bells are 10 ft in diameter. See Fig. 2. The pumps operate at a constant speed of 105 rpm and are driven by 300-hp, 1,800-rpm vertical-induction motors through reduction gears.

Each 10-ft-diameter suction bell is suspended in an 18 x 25-ft suction pit which opens directly into the tailwater pool. Movable metal stop-gates are provided to close off each suction pit independently. See Fig. 2. Since the fish swim against the current, they move away from the pump suction.

The design and operation of the north shore fish facility is similar to that just described for the south shore, or powerhouse side, of the dam. However, the attraction-water requirements are considerably less. The total pumping capacity is 750 cfs at a pool-to-pool head of 3.5 ft, supplied by three pumps in increments of 250 cfs. Worthington Corporation furnished three 96-in. pumps of the same design as those furnished for the north shore station. These units operate at 92 rpm and each is driven by a 200-hp, 1,800-rpm constant-speed motor through reduction gears.

Pull-out design

Using ordinary pump designs, with the stationary diffuser placed above the impeller, it is evident that the impeller must be removed before the shaft can be pulled out. This, of course, can only be done from below. This operation makes it necessary to dewater the pit and then remove the suction bell and impeller from below. Each suction bell is 10 ft in diameter and weighs 2,000 lb, and the impellers, about 6 ft in diameter, weigh 3,200 lb. Removal from below, working within the confines of the suction pit, where overhead cranes are not available, would be a formidable task. Watertight access openings into the suction pit large enough to remove the components would have to be provided. It is evident that the ability to remove the rotating element from above would result in substantial savings in structure, labor and down time.

To meet this need, Worthington engineers developed the pump of "pull-out" design. See Fig. 2. With this arrangement, double-barreled construction is used in the diffuser and impeller section of the pump. The outer pump barrel is permanently grouted in position and the suction bell is suspended from it. The stationary inner barrel and diffuser are supported from above and the 8-ft discharge is connected to the butterfly valve. The joining surfaces between the inner and outer barrels are corrosion-resistant rings, to eliminate any possibility of "freezing" in position.

Pull-out design makes it possible to remove the entire rotating assembly from above, including the impeller, shaft, bearings, and stationary diffuser. By avoiding pit dewatering and making it possible to use overhead cranes, pullout design reduces down time and maintenance costs.

Trend toward turbine drive

Fish attraction is a relatively new pump application, yet certain trends are already becoming apparent. Through design refinements, the total quantity of attraction water is being reduced and the trend is toward fewer but larger pumps. The required flexibility in flow is obtained by using variable-capacity pumps. Because of the extremely large size of some of the components, such as suction scoops and discharge elbows, these are often being incorporated in the concrete construction. With this arrangement the pump consists of the impeller and diffuser sections only.

The trend in driving power is toward the use of hydraulic turbines rather than electric motors. These meet the horsepower requirements of the larger pumps and, through governor control systems, can operate at variable speeds. The tailwater from these turbines is added to the pump discharge and accounts for about 10 percent of the total attraction-water requirement.

Reduction in the number of units required has made possible the installation of turbine-driven units in the powerhouse proper. This eliminates the necessity for a separate and expensive pumphouse. Because of the obvious advantages of the pull-out design, it is being incorporated in units of all sizes.