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FISH FRIENDLY PUMPING STATIONS



RAPPORT

2008
w04



Fish Friendly Pumping Stations

Principals, Practices & Outcomes in Dutch Water Management

Colophon

Publishers

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Notification

With the implementation of several European and national legislations, Dutch water managers face an increased number of obligations with regard to the quality of water systems. Solutions to rehabilitate fish migration receive an increasing amount of attention within this water quality management. This study focused on these solutions at polder pumping stations.

The first part inventoried the necessity for fish friendly pumping stations in Dutch polder water systems and the possible measures that can be utilized to create these pumping stations. The second part of this study coupled this information to the current motives of Dutch water managers whether or not to implement measures that create fish friendly pumping stations. In addition, this study assessed whether Dutch water management policy and management decisions comply with societal and legislative obligations concerning the protection of fish species and the rehabilitation of fish assemblages.

Toelichting

Waterbeheerders staan voor steeds meer verplichtingen ten aanzien van de kwaliteit van watersystemen. Een verdere achteruitgang van deze kwaliteit is niet toegestaan en er moeten maatregelen getroffen worden om een verbetering teweeg te brengen. Oplossingen voor herstel van vismigratie krijgen steeds meer aandacht binnen dit waterkwaliteitsbeheer. Deze studie heeft zich gericht op dit herstel bij poldergemalen.

Het eerste deel heeft de noodzaak voor visvriendelijke gemalen en de maatregelen, die genomen kunnen worden om gemalen visvriendelijk te maken, geïnventariseerd. In het tweede deel van deze studie wordt er een link gelegd tussen deze informatie en de motieven van waterbeheerders voor het al dan niet visvriendelijk maken van hun gemalen. Tevens is gekeken of de motieven en het huidige waterschapsbeleid overeenkomen met bestaande maatschappelijke en juridische verplichtingen.

STOWA report number 2008-W-04

Date December 2008

Preferred citation

Moria, L. (2008). *Fish Friendly Pumping Stations: Principles, Practices & Outcomes in Dutch Water Management*. STOWA 2008-W-04, Utrecht.

Preface

This report is the result of the research I performed during my internship at the STOWA (Foundation for Applied Water Research). This research internship has been the last venture of my master program Energy and Environmental Sciences. It was supervised by Bas van der Wal, research coordinator at the STOWA, and Ton Schoot Uiterkamp from the University of Groningen. I thank my supervisors for their assistance, support and editorial comments. I would also like to thank Bas for his motivating enthusiasm and the opportunities he gave me to explore the work field of water management. I have been most fortunate to have had a third supervisor, Anne Jelle Schilstra who has been of great help during my struggle to find the right course for this study.

Throughout this research I have consulted many experts. I would like to thank Marcel Klinge, Pui Mee Chan, Niels Brevé and all others, who I have discussed with during the 'Vissennetwerk' and 'Werkgroep Ecologisch Waterbeheer' gatherings for their time and expertise.

This study largely depends on the reactions and input of the water managers I interviewed. I have had pleasant and honest conversations with Dwight de Vries, Gerrit Jan van Dijk, Hanneke Maandag, Hans Roodzand, Harald Smeets, Helen Hangelbroek, Iwan de Vries, Jacques van Alphen, Jappie van den Bergs, Jeffrey Samuels, Lucienne Vuister, Marit Meijer, Peter Heuts, Rob Gerritsen, Wim de Wit and Wouter Quist. Many thanks go out to all these respondents, for their time and cooperation.

Last but definitely not least, I thank Bert, Cora, Henk, Jacques, Jet, Joost, Ludolph, Michelle, Petra and Tessa for making the STOWA a pleasant, amusing and cozy working environment.

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Samenvatting

Inleiding

In poldergebieden worden grote hoeveelheden water verpompt om wateroverlast te voorkomen. Hiervoor bevinden er zich momenteel meer dan 3000 gemalen in Nederland. Dit heeft veel voordelen voor waterveiligheid, landbouw en drinkwatervoorziening, maar er zit ook een keerzijde aan.

De manier waarop het waterpeil in polders wordt beheerd heeft namelijk grote gevolgen voor aquatische ecosystemen en daarmee voor ook voor vissen. Populaties van veel Nederlandse vissoorten zijn sterk afgenomen of zelfs uitgestorven als gevolg van het verlies van leefgebieden en migratiemogelijkheden. Gemalen spelen hierin een belangrijke rol, omdat ze een fysieke blokkade opwerpen en visschade kunnen veroorzaken.

Met de inwerkingtreding van verschillende nationale en Europese wetgevingen, zoals de Kaderrichtlijn water, staan waterbeheerders voor steeds meer verplichtingen ten aanzien van de kwaliteit van watersystemen. Een verdere achteruitgang van deze kwaliteit is niet toegestaan en er moeten maatregelen getroffen worden om een verbetering teweeg te brengen. Oplossingen voor herstel van vismigratie krijgen steeds meer aandacht binnen dit waterkwaliteitsbeheer.

Desalniettemin wordt er op dit moment weinig actie ondernomen om de problemen van vissen bij gemalen op te lossen. Daarom heeft deze studie de motieven van waterbeheerders voor het al dan niet visvriendelijk maken van hun gemalen onderzocht. Hiervoor zijn 15 waterbeheerders geïnterviewd. Tevens is gekeken of de motieven en het huidige waterschapsbeleid overeenkomen met bestaande maatschappelijke en juridische verplichtingen. Om deze link goed te kunnen leggen is er een inventarisatie gemaakt van de noodzaak voor visvriendelijke gemalen en de maatregelen die genomen kunnen worden om gemalen visvriendelijk te maken. Deze inventarisatie is gebaseerd op een literatuurstudie en gesprekken met experts.

Ecologische effecten

Alle vissen kunnen hinder ondervinden van gemalen, omdat ze deze niet kunnen passeren of beschadigd worden wanneer ze dit wel doen. Vooral vissen die over lange afstanden migreren zijn hier erg kwetsbaar voor. Een voorbeeld hiervan is de aal. Polders vormen een ideaal opgroei- en foerageergebied voor deze soort. Wanneer het volwassen levensstadium is bereikt wil aal naar het zoute water om te paaien. Op hun stroomafwaartse migratieroute van zoet naar zout water kan deze soort geblokkeerd of beschadigd worden door gemalen. Ook wanneer jonge aal landinwaarts trekt, in stroomopwaartse richting, worden ze fysiek geblokkeerd door gemalen. Overige poldervissoorten hebben weer andere beweegredenen om polders in en uit te migreren, maar kunnen vergelijkbare problemen ondervinden.

Visschade wordt voornamelijk veroorzaakt door contact met de draaiende delen en grote drukverschillen in een gemaal. Deze schade blijkt sterk afhankelijk te zijn van technische karakteristieken van het gemaal, zoals pomptype, rotatiesnelheid en het drukverloop in een pomp. Uit onderzoek is gebleken dat vooral kleine, snel roterende poldergemalen, en de twee meest voorkomende pomptypen veel schade veroorzaken.

Hoewel het duidelijk is dat individuele vissen problemen kan ondervinden bij gemalen, is het minder duidelijk of gemalen ook effecten hebben op vispopulaties of ecosystemen. Er is veel onderzoek

gedaan naar migratie van paling, maar er bestaat weinig kennis over de migratiebehoefte van andere vispopulaties die voorkomen in stilstaande wateren. Het is wel duidelijk dat de gevoeligheid van verschillende vissoorten voor de barrièrewerking van gemalen varieert. Derhalve kunnen gemalen de samenstelling van visgemeenschappen en normale predator-prooi relaties verstoren. Wanneer deze samenstelling verandert zal dit weer invloed hebben op de kwaliteit van watersystemen, omdat visgemeenschappen de troebelheid en ontwikkeling van vegetatie in watersystemen kunnen beïnvloeden.

Visvriendelijke gemalen

Er bestaan meerdere oplossingen voor de problemen die vissen kunnen ondervinden bij gemalen. Via de aanleg van vispassages langs of door een gemaal wordt vismigratie mogelijk gemaakt. Visschade kan worden voorkomen door afschrikmechanismen voor een gemaal te plaatsen of gemaalpompen te vervangen met visvriendelijk pompen. De oplossingskeuze is per situatie afhankelijk van kenmerken van het watersysteem en het gemaal.

Tot op heden is er nog maar weinig aandacht besteed aan deze oplossingen. Dit komt omdat de barrièrewerking van gemalen pas recent onder de aandacht is gekomen en omdat het visvriendelijk maken van gemalen erg complex is. Deze complexiteit wordt voornamelijk veroorzaakt door het feit dat bemalen watersystemen worden gekenmerkt door hun tegennatuurlijk waterpeil.

De aanleg van vispassages leidt hierdoor tot onherroepelijke waterverliezen en het is niet duidelijk of vissen wel door een passage willen migreren. In tegenstelling tot een natuurlijke situatie vindt stroomafwaarts gerichte vismigratie, van polder- naar boezemwater, namelijk plaats van een laag naar een hoog peil. Dit betekent dat stroomafwaarts migrerende vis tegen de stroomrichting in moet zwemmen wanneer deze door een passage migreert. Om waterverliezen te voorkomen en een natuurlijke stroomrichting in een passage te creëren zijn complexe voorzieningen met pompsystemen nodig. De lokstroom die deze pompsystemen produceren is tevens nodig om stroomopwaarts migrerende vissen naar de ingang van een passage te lokken. Hoewel vispassages migratie mogelijk kunnen maken, beschermen deze voorzieningen vis niet tegen schadelijke gemaalpompen. Visvriendelijke gemaalpompen kunnen zowel visschade voorkomen als een 'natuurlijk stroomrichting' creëren, maar vissen kunnen pompen slechts in één richting passeren. Hierom is er op dit moment altijd een combinatie van maatregelen nodig om veilige passage in zowel stroomopwaartse als afwaartse richting mogelijk te maken.

Naast het effectief laten passeren van vis zijn andere aspecten ook van groot belang bij de keuze voor bepaalde maatregelen. Hierbij valt te denken aan onderhoudsvereisten, energieverbruik, aanschafkosten, toepasbaarheid bij grote opvoerhoogten, type constructiemateriaal en levensduur van passages en visvriendelijk pompen. Bovendien kan een vergelijking van deze aspecten en de effectiviteit van visvriendelijke gemalen met andere visstandbeheersmaatregelen, waterbeheerders helpen bij het opstellen van kosteneffectieve maatregelpakketten.

Maatschappelijke en juridische verplichtingen

Er bestaan verschillende Europese en nationale wetten en regels die betrekking hebben op het beschermen en beheren van de visstand in Nederland. De verplichtingen die hieruit resulteren zijn niet altijd even duidelijk.

De verplichting die resulteert uit de Benelux beschikking vrije vismigratie is wel helder. Deze stelt dat vismigratie in 2010 mogelijk moet zijn in alle wateren van de Benelux. Er bestaat echter veel onduidelijkheid over wie de verantwoordelijkheid voor deze beschikking moet dragen, omdat deze nooit is vertaald in nationaal en provinciaal beleid.

Andere Europese richtlijnen leiden niet tot zulke bindende verplichtingen. De Kaderrichtlijn water (KRW) en Aal verordening kennen alleen een resultaatsverplichting. Waterbeheerders worden vrij gelaten in het opstellen van maatregelpakketten welke tot het gewenste ecologische herstel van watersystemen moeten leiden. Omdat er beperkt onderzoek is gedaan naar de ecologische effecten van gemalen is het moeilijk om het visvriendelijk maken van gemalen te koppelen aan dit herstel. De KRW stelt echter wel dat een verdere achteruitgang van de kwaliteit van watersystemen niet is toegestaan. Dit betekent dat er geen verslechtering van de visstand mag optreden na nieuwbouw of renovatie van gemalen. Bovendien bestaan er verschillende argumenten die het visvriendelijk maken van gemalen verbinden aan een verbetering van de visstand in polder- en boezemsystemen. Deze kunnen gebruikt worden bij het opstellen van maatregelpakketten voor de KRW, de Flora en Faunawet, de Aal Verordening en de Vogel en Habitat richtlijnen.

Beleidsanalyse

Waterbeheerders zijn zich over het algemeen bewust van de problemen die vissen ondervinden bij gemalen en van de maatregelen die bestaan om deze op te lossen. Men is het er over eens dat individuele vissen hinder ondervinden bij gemalen, maar er bestaat scepsis over de effecten van de gemalen op populatie- of ecosysteemniveau.

De kosteneffectiviteit en haalbaarheid van maatregelen staan ook nog ter discussie. Het feit dat maatregelen voor veilige vispassage altijd op maat moeten worden gemaakt, omdat elkemaal andere karakteristieken heeft, wordt gezien als belemmering voor de implementatie van maatregelen. Het robuust beheersen van waterpeilen wordt belangrijker geacht dan het beschermen van vissen. Technici lijken daarom liever te kiezen voor op grote schaal toegepaste, bewezen technieken.

Waterbeheerders zijn niet altijd op de hoogte van bestaande verantwoordelijkheden en verplichtingen. Dit kan zijn omdat zij zich niet bewust zijn van bestaande wetten en regels of omdat men de relatie tussen deze wetgeving en de ecologische effecten van gemalen niet kent.

De in deze studie vertegenwoordigde waterschappen hebben al beleid geformuleerd ten aanzien van vismigratie, maar dit nog niet geïmplementeerd. Hierdoor voldoen zij op dit moment niet aan bestaande verplichting. Er zijn geen maatregelen genomen om vismigratie mogelijk te maken bij gemalen en er worden nog steeds nieuwe gemalen aangelegd die niet visvriendelijk zijn. Er bestaat echter veel onduidelijkheid over de exacte verantwoordelijkheden en verplichtingen die uit verschillende wetgeving resulteren. Eén nationale beleidslijn zou meer duidelijkheid over deze verantwoordelijkheden en verplichtingen kunnen verschaffen. Deze beleidslijn kan tevens een belangrijke fundering vormen voor de onderbouwing van beslissingen om gemalen al dan niet visvriendelijk te maken.

Er ontbreekt nog veel kennis over de barrièrewerking van gemalen, de effectiviteit van maatregelen en het belang van visvriendelijke gemalen voor het realiseren van beleidsdoelstellingen. Waterbeheerders hebben behoefte aan objectieve informatie over deze onderwerpen. Op dit moment vormen deze kennishiaten een belemmering voor het implementeren van maatregelen. Deze hiaten kunnen alleen worden weggenomen door 'visvriendelijke' maatregelen te implementeren en de effecten hiervan te meten. Bovendien kan het implementeren van maatregelen visvriendelijke technieken de gelegenheid geven zichzelf te bewijzen.

Executive summary

In the Netherlands polder water levels are managed with almost 3000 pumping stations that pump excess water from polders to reservoir canals or sea. These pumping stations might threaten Dutch fish stocks. Migrating fish are often unable to pass a pumping station and pumps can damage or kill fish when they do pass through.

Since pumping stations fulfil an important role in drainage control, it is most often not possible to remove them. Therefore various technical solutions have been developed to facilitate fish passage and prevent entanglement. These measures can result in so-called fish friendly pumping stations. The effectiveness of and necessity for fish friendly pumping stations remains largely unknown. Hence, the first part of this study assessed the knowledge about the ecological effects of pumping stations and the possible measures that can be utilized to mitigate these.

While there are many regulatory incentives which concern the protection of fish species and the rehabilitation of fish assemblages, little action is undertaken by water managers to implement measures. For this reason the second part of this study assessed the motivation of regional water manager whether or not to implement these measures. Fifteen water managers, who were selected for their knowledge about fish migration, were interviewed to determine these motives.

Hazards and obstacles

Fish may migrate in downstream direction¹, because some species prefer deeper reservoir canals to hibernate during winter or because some species need to spawn in sea. Pumping stations can induce damage, create a delay in or obstruct migration in this direction. Fish migration is delayed or obstructed for fish that are deterred by sound and vibration or too large to pass through waste collection structures. When fish pass through a pumping station, damage can occur as a result of collision with mechanical parts or exposure to fluctuating pressures and turbulence within the pump. This damage can vary greatly and depends on the pump type that is utilized. Especially the two most frequently utilized pump types, axial and centrifugal pumps, are known to result in much damage. Small sized polder pumping station that operate with a high rotation speed are very harmful as well. Fish survival is also influenced by species, size, life-stage, and the physiological condition of fish.

Fish may migrate in upstream direction², because some fish species prefer shallow, vegetation-rich polder waters to spawn or shelter. Pumping stations can obstruct migration in this direction as well. Water inlet structures, which are often present within polders, can provide an alternative route for upstream migrating fish. However, fish are probably attracted by the flow produced by a pumping station. One might argue that fish are therefore more inclined to gather at pumping stations than at inlet structures that are located elsewhere.

It is less obvious whether pumping stations also affect fish populations or complete assemblages. Diadromous species, such as eels and three spined stickleback are most likely affected on a population scale. These species must be able to migrate between salt and fresh water in order to fulfill their lifecycle

¹ Downstream migration is directed from fresh water towards sea or from a polder areas towards a reservoir canals

² Upstream migration is directed from sea towards fresh water or from reservoir canals towards polder areas

and might come across multiple damaging pumps along their migratory route. Fish species that need large areas for their lifecycle fulfillment and species with a low tolerance to habitat fragmentation are also more likely to decrease in numbers than other fish species. Due to this variety in sensitivity of fish species, the composition of fish communities can be altered and ordinary competition and predator-prey interactions can be influenced. Indirectly, pumping stations might even influence the water quality as a whole since altered fish communities can affect the turbidity and vegetation within water systems.

Solutions for the hazards and obstacles posed by pumping stations

The development of effective migration facilities for pumping stations is very difficult and complex. In order to create a truly fish friendly pumping station, both the obstruction and the hazard posed should be diminished. At the moment, fish friendly pumping stations are only created when a combination of measures is used. The effectiveness, costs and feasibility of available measures are strongly influenced by site specific features, but little documentation on these features exists. It can however be concluded that pumps that are adapted as such that fish are able to pass safely, are most promising in terms of energy utilization, costs and maintenance.

It is important that maintenance requirements, energy utilization, capital costs, applicability at high heads, type of required construction materials and the lifetime of measures will be determined. A comparison of different 'fish friendly' measures, based on these criteria could provide an overview of the sustainability of fish friendly pumping stations. Furthermore, an examination of the cost effectiveness of 'fish friendly' measures in comparison to other measures which aim to improve fish stocks could aid water managers in their choice between different measures.

Policy obligations

The protection of fish species and the rehabilitation of fish assemblages is embedded in the Flora and Fauna law, the European Water Framework Directive (WFD), the Habitat Directive, the Benelux decision regarding free fish migration and the European Eel Regulation. The responsibilities and enforcement resulting from these legislations are often not clear.

Stringent obligations result from the Benelux decision and the targets set for the Ecological Network. Within the Benelux decision a clear objective is stated; fish migration needs to be enabled in all water bodies by 2010 (Benelux Economical Union, 1996; Nijboer, 2000). This is reinforced by the objectives stated for the areas representing the Dutch Ecological Network (EHS). However, it remains ambiguous who is responsible for the implementation of the Benelux decision, since it has never been incorporated into national policy.

The responsibilities and enforcement which results from other European directives are apparent, since these are translated into national policy. Nevertheless, these legislations cannot be directly connected to the hazards and obstacles posed by pumping stations, since assessments of the ecological effects of pumping stations are scarce. The WFD does not require member states to implement explicit measures, but obliges water managers to achieve their defined objectives. The measures which are necessary to achieve these objectives are determined by water managers themselves. However, the WFD prescribes a so-called stand still principle which implies that no further deterioration of water quality is allowed. Hence, one might argue that the implementation of fish friendly measures is at least

required at the construction and renovation of pumping stations. Moreover, there are several arguments which can associate fish friendly measures to defined objectives for the WFD, Eel Regulation and Habitat and Bird Directives. These arguments can be used to ground decisions to implement these measures within programs of measures for these European Directives.

Policy analysis

The interviewed water managers were generally aware of the possible hazards and obstacles posed by pumping stations and of the possible measures to solve these. Although most of them believed that individual fish are affected, not all believed that pumping stations can significantly affect fish communities and water quality as a whole. Moreover, managers were sceptical about the cost effectiveness and feasibility of measures. The fact that measures always need to be tailor made, due to the large diversity in characteristics of pumping stations is seen as an important obstacle for the implementation of measures. In addition, managers stated that technicians tend to prefer widely utilized, proven techniques since drainage control is considered more important than the concerns about fish.

Even though many laws and legislations are applicable to the protection of fish species and fish stock management, not all water managers were aware of all their responsibilities and obligations. This can be either because water managers are not aware of all existing legislations or because they do not approve the relation between those legislations and the ecological consequences of pumping stations.

One might argue that the water boards approached in this research do not comply with all existing obligations, since no efforts have been made to enable fish migration at pumping stations. Most water boards did already formulate a policy for fish stock management or fish migration. However, none of these policies have officially come into force yet. More clarity about the responsibilities and obligations resulting from applicable legislations is needed as a foundation for the grounding of decisions whether or not to implement measures. Well defined and surveyed national policy could provide a joint guideline for all water boards.

The aim of the implementation of measures should not only lay within the rehabilitation of fish communities, but also in their contribution to the assessment of ecological effects of pumping stations. A learning-by-experience process can provide valuable information and thereby reduce some of the existing uncertainties. Furthermore, the implementation of measures enables 'fish friendly' techniques to prove themselves.

Glossary & abbreviations

| | |
|-----------------------------|---|
| Amphidromous species | Fish whose migration between fresh and sea water is not for the purpose of breeding |
| Anadromous species | Fish species that spend most of their life cycle in the ocean, though they spawn in freshwater |
| Benthivore species | Fish species which diet consists of more than 75% benthic organisms. These species sometimes have a highly protractile mouth that is used to filter feed on sediments |
| Catadromous species | Fish species that migrate from fresh waters, where most of their life cycle is fulfilled, to spawn in the ocean |
| Cavitation | Formation of vapor bubbles in a liquid, which produce a shock wave when they collapse |
| Diadromous species | Fish species that migrate between sea and freshwater |
| Downstream migration | Migration directed from fresh water towards sea or from a polder areas towards a reservoir canals |
| EHS | Dutch Ecological Network (Ecologische Hoofdstructuur in Dutch) |
| Elver | An eel in its transparent, post larval stage. Also called glass eel |
| Entrainment | Process whereby fish, fish larvae or eggs are imbibed in a turbine or pump |
| Eurytopic species | Fish species that exhibit a tolerance to different flow conditions |
| Fish friendly pump | Pump that is fish passable and in which fish survive when they pass |
| Fish passable pump | Pump that is passable for fish in both up- and downstream directions |
| Fish survivable pump | Pump that does not induce fish damage or mortality |
| Former flood plains | Flood plain separated from the sea or river by a dike (Indijking in Dutch) |
| Former marshland | Drained marshes which are separated from the surrounding water by a dike (Ontginning in Dutch) |
| Impeller | A rotor inside a tube. This rotating component of a centrifugal pump increases the pressure and flow of a fluid |
| Impingement | Process which occurs when a fish contacts a waste rack or waste which is present near the entrance of pumps or turbines |
| Land reclamation | Land reclaimed from a lake or the sea bed (Droogmakerij in Dutch) |
| Lentic water system | A freshwater habitat characterized by slowly moving water |

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| Limnophilic species | Fish species that prefer to live, feed and reproduce in a habitat with slowly flowing to stagnant conditions |
| LNV | Ministry of Agriculture, Nature and Fisheries |
| Lotic water system | A freshwater habitat characterized by swiftly moving water |
| Physoclistic species | Fish that lack a direct connection (pneumatic duct) between the swim bladder and the esophagus. These species adjust the pressure within their swim bladder by diffusion of gases from the blood |
| Physostomous species | Fish that have a pneumatic duct which connects the swim bladder with the esophagus. In these species gas can be quickly exchanged from the swim bladder through this duct |
| Planctivorous species | Fish species that feed on zooplankton |
| PLONS | Dutch acronym for long term research project concerning the ecological functioning of Dutch ditches (Project Langdurig Onderzoek Nederlandse Sloten) |
| Polder | A low-lying tract of land enclosed by embankments known as dykes, which form an anthropogenically managed hydrological entity |
| Potamodromous species | Fish species that migrate within freshwater |
| Reservoir canals | Artificial canal system without a set water level, these canals admit and discharge drained water from lower lying polders (Boezem in Dutch) |
| Rheophilic species | Fish species that prefer to live in a habitat with high flow conditions, and clear water using this habitat both for breeding and feeding purposes |
| Rheotaxis | An inherent compensation movement of fishes against the current |
| Shear force | Force acting parallel to plane |
| STOWA | Foundation for Applied Water Research |
| Upstream migration | Migration directed from sea towards fresh water or from reservoir canals towards polder areas |
| VBC | Fish stock management commission (Visstandbeheerscommissie in Dutch) |
| VROM | Ministry of Housing, Spatial planning and the Environment |
| V&W | Ministry of Transport, Public Works and Water Management |
| WFD | Water Framework Directive |

1. Introductory

1.1. Introduction

A large fraction of freshwater fish species in the Netherlands is seriously threatened. No less than twenty four of all native Dutch species are red listed freshwater fishes in the Netherlands. Moreover, seven of these species have become virtually extinct (De Nie, 1997). This decline in fish species abundance and diversity is associated with alterations in the aquatic environment, exploitation of fish stocks, pollution, global climate change and exotic fish introductions (Aloo, 2003; Reeze *et al.* 2005).

Dutch water managers identified the numerous hydraulic artefacts present in their waters as an important cause of the decline in fish species abundance and diversity (Kroes *et al.* 2008). These artefacts exist in many forms and can physically obstruct migration between different habitats. Moreover, artefacts that contain water intake facilities can also damage downstream migrating fish. Damage can occur as a result of collision with mechanical parts, turbulence within a pump and exposure to fluctuating pressures (Turnpenny, 1998; Gerompé *et al.*, 1994).

It is most often not a possible option to completely remove pumping stations, since they fulfill an important role in drainage control for human safety, agriculture and infrastructure. Therefore different technical solutions are available to facilitate fish passage and prevent entanglement. Measures proposed to restore fish migration include: bypass channels on or around artificial barriers and so-called fish-friendly pumping stations (Kroes *et al.*, 2006).

The removal of barriers can positively influence migratory fish species, however it might negatively influence species that depend on isolated circumstances (De Jong, 2004). Fish migration can therefore affect the structure of fish communities. Little is known about the exact effects of pumping stations and fish-passable facilities on individual fish, let alone on a community scale. Most studies evaluating fish-passable facilities primarily assess whether individual fish species succeed in passing through. Moreover, little consideration is given to the passage and protection requirements of species that spend their entire lifecycle in freshwater. Hence, the first part of this study will assess the knowledge about the ecological effects of pumping stations and the possible measures that can be utilized to mitigate these.

There are several European and national legislative incentives concerning the protection and improvement of Dutch fish stocks. In the year 2000 the European Water Framework Directive (WFD) was issued, strongly emphasizing sound ecological management of water in its Member States. Fish stocks are one of the 'biological quality elements' within this framework. The removal of migration barriers is proposed as a measure to reach such a good status (Kroes *et al.*, 2008). The protection of fish species and the restoration of habitat connectivity and accessibility is also embedded in other legislative frameworks. Examples are the Habitat Directive, the BeNeLux decision and the European Eel Regulation.

Even though many laws and legislations are applicable to the protection of fish species and fish stock management, little action is currently undertaken to solve the bottlenecks for fish migration at pumping stations (Kroes *et al.*, 2008). It is unclear what motivates water managers to decide whether or not to implement solutions for the hazards and obstacles posed by polder pumping stations in the Netherlands. Ambiguity also exists about the compliance of this lack of action with the existing societal and legislative obligations concerning fish protection and migration. Hence, the second part of this study

will assess the motivation of water managers to integrate solutions for the hazards and obstacles posed by polder pumping stations into their water management policy and management decisions.

1.2. Problem definition

Societal and legislative concern, regarding bottlenecks for fish migration presented by pumping stations is growing. Although regulatory incentives are present, the dimension of and solutions for these bottlenecks are ambiguous. It is unknown what motivates water managers to decide whether or not to implement solutions for the hazards and obstacles posed by polder pumping stations in the Netherlands. The question whether this lack of action is in compliance with current laws and regulations also remains.

1.3. Aim

The aim of this study is threefold. First, to assess the motivation of water managers whether or not to implement solutions for the hazards and obstacles posed by polder pumping stations. Second, to assess whether water management policy and management decisions correspond with the existing societal and legislative obligations with regard to fish protection and migration. Third, to identify important knowledge gaps concerning the need and necessity for these solutions.

1.4. Research Questions

What are the motives that lead to the decision whether or not to implement solutions for the hazards and obstacles posed by polder pumping stations in the Netherlands?

How do Dutch water management policy and management decisions comply with societal and legislative obligations with regard to fish protection and migration?

1.5. Sub Questions

What is known about the ecological effects of the hazards and obstacles posed by pumping stations?

What are possible measures to solve the hazards and obstacles posed by pumping stations and what is known about their effectiveness and feasibility?

What are the societal and legislative needs to solve the hazards and obstacles posed by polder pumping stations in the Netherlands?

1.6. Boundaries

This study focuses on the hazards and obstacles posed by polder pumping stations and solutions for these specific bottlenecks. Polder pumping stations are defined as pumping stations that are utilized for water level management, and that pump water from polder waters to reservoir canals. Land reclamations, former marshlands and former floodplains are accounted for as polders. In this study, an ecological effect refers to the functioning of polder fish assemblages and the protection of individual fish

species. European and national legislative frameworks concerning fish stock management, fish species protection and animal protection are accounted for, since these provide similar obligations for all water boards.

1.7. Methods

This study can be divided in an inventory and a water management and policy analysis. The inventory consists of a determination of the ecological effects of the hazards and obstacles posed by pumping stations. The societal, management and policy situation related to these ecological effects was also inventoried. The possible measures to solve the hazards and obstacles posed by pumping stations were determined as well. Information for the inventory was provided by literature and expert consultations.

In the management and policy analysis, managers and policy makers from water boards were interviewed to determine the motives that lead to the decision whether or not to implement solutions for the hazards and obstacles posed by polder pumping stations in the Netherlands.

Only those boards that manage polders and polder pumping stations are represented. Respondents from these boards were chosen as such, that they are familiar with fish migration and hazards and obstacles posed by pumping stations. A list of water managers that are involved in the PLONS project (Project Langdurig Onderzoek Nederlandse Sloten) was used as a foundation for the respondents chosen, since most boards that manage polders are represented in this list. PLONS is a long term research project concerning the ecological functioning of Dutch ditches (Peeters *et al.*, 2006). The assumption was made that these respondents are informed of their boards' management and policy concerning hazards and obstacles for fish. Fifteen water managers were interviewed. The complete list of represented water boards is presented in chapter seven and indicated in dark green in figure 1.



Figure 1: Represented Water boards

A questionnaire for the interviews was made in advance and was reviewed by an expert on interviewing to check its consistency. An adjusted questionnaire was only sent in advance when the respondent requested it. The questionnaire was divided into three components, based on those

suggested by the corporate sustainable performance model; principles, practices and outcomes (Steg *et al.*, 2003).

For each component a core question, which has to be answered during the interview, was formulated. This question was used as the foundation for the development of the questionnaire containing open-ended questions. Additionally, respondents were asked to grade the seriousness of ecological, economic and social consequences of pumping stations. The Dutch questionnaire is included in appendix 1. The results of the questionnaire are verified with the respondents interviewed. After which they are used to determine the motives that lead to the decision whether or not to implement solutions for the hazards and obstacles posed by polder pumping stations in the Netherlands. Furthermore it is assessed whether these management decisions correspond with societal and legislative obligations with regard to fish protection and migration.

1.8. Outline

The chapters in this report correspond to the research questions stated above. In the inventory, the sub questions are answered and in the policy analysis the main research questions are answered. In chapter 2 the studied system is described. Hydrological, technical and ecological aspects are considered here. In chapters 3-5 the inventory results are described and chapter 6 concerns the policy analysis.

The third chapter focuses on the hazards and obstacles posed by pumping stations. This chapter first describes the effects of pumping stations on individual fish. After this the effects on a population scale are discussed. In chapter 4, measures which are proposed to prevent or mitigate the hazards and obstacles provided by pumping stations are stated. The merits and demerits of these measures are considered as well. In chapter 5, the societal and legislative wishes and demands with regard to fish migration are described. The interview results are described in chapter 6. This report is finalized with conclusions, a discussion and recommendations in chapter 7.

2. Dutch polders & pumping stations; system description

In this chapter the studied system is described. Hydrological, technical and ecological aspects are considered below. A definition of Dutch polders is given, after which the hydraulic aspects of the most frequently utilized pumping stations are described. This chapter ends with a description of the habitat requirements and migratory behavior of typical Dutch polder fish.

2.1. Dutch Polders

The English saying: '*God created the world, but the Dutch created the Netherlands*', illustrates the importance of polders in the Dutch landscape. A polder is defined as 'a low-lying tract of land enclosed by embankments known as dykes, which form an anthropogenically managed hydrological entity' (Hooghart, 1986). There are three types of polders: land reclamations, former floodplains and former marshlands. Land reclamations are polders wherein land which was originally submerged lake or seabed, is actually reclaimed from the water. The latter two types of polders are lands that are separated from the surrounding water by dykes. Water level management in these areas depends on ground water levels within the polder and ground level (Fockema Andreae *et al.*, 1958; Groote, 1995). Figure 2 gives a schematic illustration of two of these polder types. Former floodplains are not included since these are similar to land reclamations; The main difference is that floodplains are often located on higher sand grounds.

Water can enter a polder through groundwater seepage, rainfall and transportation of water by rivers and canals. This generally means that polders have an excess of water. Polders are characterized by a hydrologic system in which excess water is pumped from polders to reservoir canals and in times of water shortages water is submitted back to polder systems (Verdonschot *et al.*, 1997).

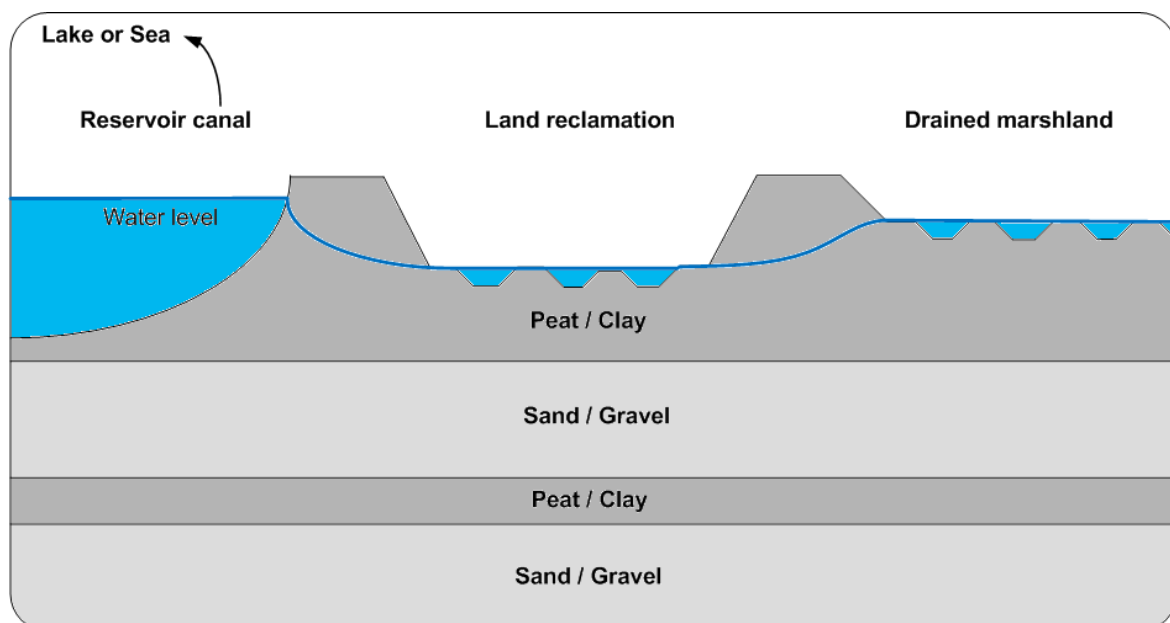


Figure 2: Cross-section of typical Dutch hydrological polder-reservoir systems (land reclamation and drained marshlands)

Some polders have a similar or higher water level than their adjacent reservoir lands. Especially, those located in areas on higher sand grounds and along coast (former floodplains). These type of polders do not need to be drained by pumping stations, since water can be transported by gravitational discharge (Fockema Andreae *et al.*, 1958; Grootte, 1995). The ground level in drained marshes subsides over time, therefore these type of polders will eventually be below the surrounding water level. The internal water level greatly influences this process, since former marshlands will show accelerated compression due to the peat decomposing in dry conditions. Most polders have a lower water level than their adjacent reservoir lands (Best & Bakker, 1993).

Polder ditches and canals encompass approximately three quarters of all regional waters in the Netherlands and are mostly located in the northern and western parts (Holocene) of the Netherlands. Polder ditches are characterised by their small, shallow and straight shaped structures. The depth of polder ditches is often less than 1.5 meters and their maximum width is 8 meters. Two typical characteristics of polder water systems is their large bilateral connectivity through surface waters and the large differences between the chemical composition of admitted and submitted water (Verdonschot *et al.*, 1997; Nijboer, 2000).

Ditches and canals are mostly viewed as infrastructural water bodies, but their inherent ecological value and purifying function is also very important (De Jong, 2002; Peeters *et al.*, 2006). The 300.000 km of polder ditches in the Netherlands, encompass a large fraction of typical Dutch flora and fauna, and fish communities in these polder systems can be unique. Worldwide, these type of water bodies are rare and can therefore be considered important to preserve (Verdonschot *et al.*, 1997; Peeters *et al.*, 2006).

2.2. Pumping stations

In the Netherlands water levels are managed with more than 3000 polder pumping stations (Kroes *et al.*, 2006). Besides large reservoir pumping stations, that pump water from reservoir lands to sea or lake IJssel, there are many polder pumping stations that pump water from polders toward reservoir canals and within polder systems (Vegter & Punter, 2005). Hence, polder pumping stations can both replenish at reservoir canals or directly at sea. Some pumping stations have an inlet sluice to submit water into a polder system in times of shortages. These sluices can also be located elsewhere in a polder.

Polder pumping stations are mostly small with only a single pump, though larger stations exist as well. Due to the large differences in required capacity and suction height, different pump types exist. In the Netherlands most pumps are of a (open and closed) axial screw, Archimedes screw or centrifugal type (Kruitwagen & Klinge, 2007). Figure 3 illustrates the flow direction within such axial and centrifugal pumps and an Archimedes screw. All these pumps have their own merits and demerits.

An axial screw pump is a rotating pump in which movement of the fluids is obtained along a pointed cavity. This type of pump consist of a housing in which blades rotate (propeller) to creates suction forces to move water. The pressure difference created by the rotation of the screw forces water upwards. Fluid trapped between the blades and inner surface of the cylindrical casing is forced in the axial direction towards the discharge end. It is simple in structure and small in external dimension. These type of pumps are most suitable for large pumping rates and low heads (Gerompé *et al.*, 1994). The hydraulic efficiency of screw pumps can be very high, because leakage and internal friction is low. Another advantage of these pump types is that very little noise is produced. However, these type of

pumps are prone to cavitation and clogging by wastes because the propellers will bend or possibly break if they strike a relatively large, hard objects and fibrous material will wrap itself around the propellers (Fraenkel, 1986).

The Archimedes screw pump can undoubtedly claim to be the oldest pump for the transportation of liquids. In the third century before Christ Archimedes, the Greek mathematician and scientist invented the 'Archimedes screw' which was utilized to lift water. Each screw thread is matched to carry a specific volume of fluid. Fluid is transferred through successive contact between the housing and the screw blades from one thread to the next (Rorres, 2000). These type of pumps have proven to be stout and have a high hydraulic efficiency. Moreover, this type of 'pump' is not prone to waste clogging. However, Archimedes screws are not suitable for situations in which large pumping rate is required or for higher heads. A screw pumping station is also large, noisy and visually intrusive (Fraenkel, 1986).

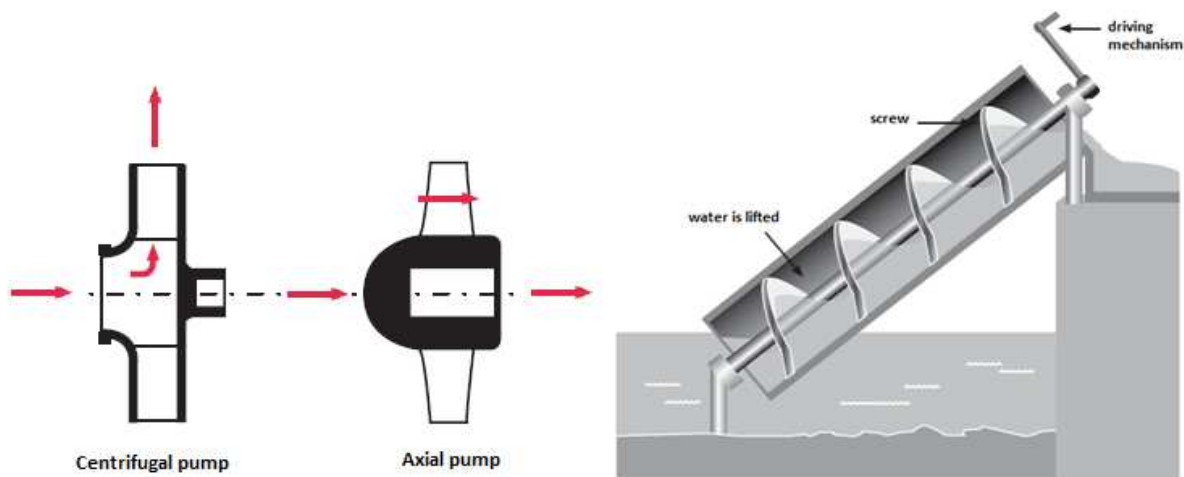


Figure 3: Axial flow, Centrifugal flow, the red arrows indicate flow direction, & Archimedes screw (Source: WILO pump Intelligenz)

In centrifugal pumps fluid is moved by centrifugal forces. Water is forced into the pump by the pressure decrease created by a rotating impeller. Water enters the pump in axial direction and is moved by centrifugal forces in radial direction. These pump types are most suitable for higher heads and pumping rates (Fraenkel, 1986). Centrifugal pumps generally handle debris quite well. However, the waste handling capability decreases with an decrease in the size of the impeller opening and increase in the number of blades. Due to the high pressure involved, design of a centrifugal floodwater pumping station and its associated rising mains should be carried out carefully to avoid hydraulic problems caused by cavitations (Gerompé *et al.*, 1994).

2.3. Polder fish

It is difficult to define a "natural" polder fish ecosystem, since polder waters are manmade and no natural reference situation is present. Polder ditches are often seen as the smaller capillaries of unnatural polder water systems, which correspond with small streams as the capillaries of larger natural catchments (Otburg & Higler, 2003).

Polder ditches are also compared to shallow lakes, since polder waters are also characterized by lentic waters. Since water enters a polder in the from rain and ground water, ditches sometimes also comprise characteristics of lotic waters. Due to their commonly lentic conditions and little shade present, typical ecosystem in polders can be vegetation rich (Evers *et al.*, 2007). Therefore polders provide ideal conditions for limnophilic species and spawning habitats for phytophile species. The typical polder species

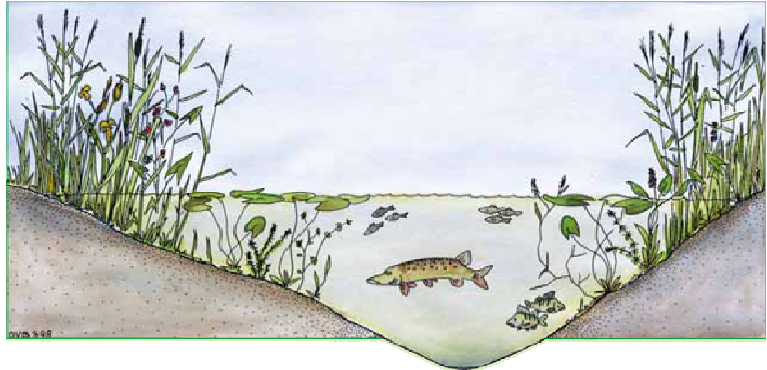


Figure 4: Lentic polder waters provide ideal conditions for Pike-roach fish assemblages

considered in table 2 (appendix 2) are selected on basis of their occurrence in the Water Framework Directive objectives for ditches and canals, Habitat Directive and Flora and Fauna law, since these are considered important indicators and protected polder species. Specific requirements related to migratory behaviour of these polder fish are further explained below and given in table 2.

Fish can be classified according to functional guilds. The functional guild concept denotes that the fish community structure is determined by the functional diversity of an aquatic habitat, in terms of habitat availability and prevalent hydrological processes. This guild approach arranges a community on the basis of common ecological requirements. In the Netherlands, one of the oldest, and most generally applied, ecological classifications of fish species is the one based on the flow preference and migratory behaviour of adult fishes (Aarts & Niehuis, 2003). Below both habitat requirements and migratory requirements are specified in terms of this functional guild concept.

2.3.1. Habitat requirements

Habitat requirements are those characteristics of habitats needed for the long term survival of fish species. The bitterling (*Rhodeus sericeus*), for instance, requires the presence of freshwater mussels for spawning, since it lays its eggs in the mantle cavity of these bivalves (Van Emmerik & de Nie, 2006). If this requirement is not fulfilled, the population can go extinct. Habitat preferences are those habitat characteristics a species will utilize more frequently than would be expected according to its availability. For example, bream (*Abramis brama*) prefers small substrate sizes, since this enhances the efficiency in which it can filter food particles from sediment (Lammens & Hoogenboezem, 1991). Thus when bream has a choice between habitats with fine and coarse substrate sizes it will most often choose the habitat with finer sediment size if all other factors are equal.



Figure 5: Spawning bitterling

Important factors which determine the habitat characteristics of a lentic water system, are its flow rate, depth, substrate, size of the area that is accessible, and vegetation present. These factors again influence water temperature, oxygen availability, food availability and the type of refuges present (Ottenburg & Higler, 2003; Morrow & Fischenich, 2000). In table 2 (appendix 2) these important habitat characteristics of polder fish are given. Within this table several habitat characteristics are defined as functional guild types.

2.3.2. Migration

Fish migration occurs along different distances and is triggered by different motives. Migration is often a seasonal phenomenon, which occurs in order to move between necessary habitats, such as winter refuges and spawning or nursery habitats. Kroes *et al.* (2006) state that 'The distance of migration can vary between species, within populations of the same species or even within one population of a species'.

In literature the terms 'movement', 'migration' and 'dispersion' are generally used to describe different types of migratory behaviour of fish. The term movement is more suitable to describe movements within territories and home ranges, while the term migration is used to describe strongly directional movements that result in a change to different, separate habitats (Kroes & Monden, 2005; Van Liefferinge *et al.*, 2004). Dispersion is a local population-scale event, while migration refers to the movements of individual fish (Van Liefferinge *et al.*, 2004; Lucas, & Barras, 2001).

The most explicit motive of fish migration to and from polder water bodies concerns reproduction. Fish might also migrate between different habitats for feeding and hibernation. Movements within habitats, as fish move between refuges and feeding areas often occur along shorter distances and time scales. Fish movements are also undertaken to escape threatening environments such as water pollution, high water temperatures, low oxygen concentrations, high- and low river discharges and drying out of river sections (FAO & DVWK, 2002; Coeck, 2002 ; Kroes & Monden, 2005). These escapes affect the survival of fish populations and can therefore be classified as 'dispersion'. Dispersion between populations is also necessary to avoid inbreeding. Small isolated populations are vulnerable to local extinction, even when the environment is appropriate. Dispersion allows for habitat expansion and colonization of new waters (Van Liefferinge *et al.*, 2004; Lucas & Barras, 2001).

Fish migrations can occur in longitudinal, lateral and vertical direction. Longitudinal migrations occur in up- and downstream direction while lateral migrations are movements from river to floodplain and vice versa. Lateral migrations are often followed by longitudinal migrations (Kroes *et al.*, 2006).

Strictly speaking polder water systems are mostly characterized by stagnant waters and the distinction between up- and downstream and water moving in lateral direction cannot be made similarly as for natural river systems. Polders are often referred to as the capillaries of artificial water systems or the replacement of natural inundated areas in an artificial water system. Therefore, migrations from reservoir lands towards polders can sometimes be considered as longitudinal, for example when the migration of eel (*Anguilla Anguilla*) is considered, and sometimes as lateral, for example when the spawning migration of pike (*Esox lucius*) is considered. Vertical migrations of adult fish are not considered in this study as polder water systems are characterized by their shallow structure.

Migration and especially spawning migrations are often restricted to a specific periods and triggered by fish biology (internal stimulus) and environmental conditions (external stimuli). Internal

stimuli are hormonal changes, experience, learning and desire for food. External stimuli are factors such as food availability, presence of predators and abiotic factors as temperature, light, lunar cycles, weather conditions and flow velocity (Lucas, & Barras, 2001; Kroes, & Monden, 2005). Each species and sometimes even each population has a unique migration patterns, with different stimuli and migration periods. Due to this diversity, migrations can occur throughout the year.

The orientation of fish is often based on so-called rheotaxis. Rheotaxis is an inherent compensation movement against the current. It prevents the fish from being drifted with the current. Positive rheotaxis means a fish has the tendency to swim in upstream direction, negative rheotaxis is oriented downstream (Pavlov, 1979; Pavlov *et al.*, 2008). Little is known about other orientation mechanisms of fish, though vision or touch and lateral line organs are other orientation mechanisms which enable fish to find their way (Lucas & Barras, 2001). Eel is also known for its strongly developed scent (Riemersma & Wintermans, 2005).

There are two types of migratory guilds. There are those fish that migrate between the sea and freshwater, called diadromous fishes, and those species that migrate within freshwater, called potamodromous fishes. Diadromy can be further divided into three sub-categories: anadromous, catadromous and amphidromous species. Anadromous species spend most of their life cycle in the ocean, though they spawn in freshwater. Catadromous species migrate from fresh waters, where most of their life cycle is fulfilled, to spawn in the ocean. Fish whose migration between fresh- and sea water is not for the purpose of breeding are referred to as amphidromous (McDowall, 1997; Aarts & Niehuis, 2003). Fish that are not considered strictly diadromous can also show migratory behaviour. This can be explained by their flow guild, reproduction guild or by the triggers for movements and dispersion explained above. Fish species can be classified in both migratory and flow preference guilds. Eel, for example, can be placed in both categories diadromous and eurytope. In table 2 (appendix 2) migratory guilds of typical polder fish are given. In most practical applications, e.g. WFD, each species is placed in only one category.

3. Hazards and obstacles posed by pumping stations

This chapter considers the hazards and obstacles posed by pumping stations. Pumping stations form a barrier when fish migrate toward a polder (upstream migration), since they are unable to pass physical barrier formed. Damage and mortality due to passage through pumping stations can occur when fish move from polder waters to adjacent canals (downstream migration). Moreover, pumping stations can create a delay in, or completely obstruction migration in this direction for fish that are deterred by sound and vibration or too large to pass through waste collection structures (De Lange & Merckx, 2005; Merckx & Vriese, 2006; Kroes & Monden, 2005).

3.1. Damage and mortality

The construction of pumps utilized in pumping stations is comparable with turbines in hydroelectric power plants. Therefore studies on mortality rates at hydroelectric turbines and pumps are both considered here. The main difference between hydroelectric turbines and pumping station pumps is that turbines generate energy from descending water, while pumping stations utilize energy for the lifting of water. These difference are shown in figure 6.

Studies on damage and mortality due to turbine passage already started in the late 1930s. Most of these studies focused on anadromous salmon (*Salmo salar*) and catadromous eels in hydroelectric turbines (U.S. Office of Technology Assessments (OTA), 1995). Subsequently experimental efforts extended to fish passages at cooling water intakes and most recently research has also been performed at pumping stations. These latter studies also include fish species other than diadromous species. The results from mortality experiments largely differ.

Turbine and pump mortalities estimated, vary from 0% to 100%

(Kruitwagen & Klinge, 2008; Kroes et al., 2006; Kruitwagen et al., 2006; Riemersma & Wintermans, 2005; Kruitwagen & Klinge, 2007; Merckx & Vriese, 2006; Lange & Mekx, 2005; Germonpré et al., 1994; Denayer & Belpaire, 1992; Hadderlingh, 1979; Therrien & Bourgeois, 2000; Larinier, 2001; Bruijs, 2004; Cada et al., 2008; Turnpenny et al., 1998; Acres international corporation, 2005; Vriese, Klein Breteler, Kroes & Spierts, 2007).

Table 3 (appendix 2) summarizes the results of some of these studies executed in the Netherlands and Belgium. Several studies have identified that the damage and mortality induced during

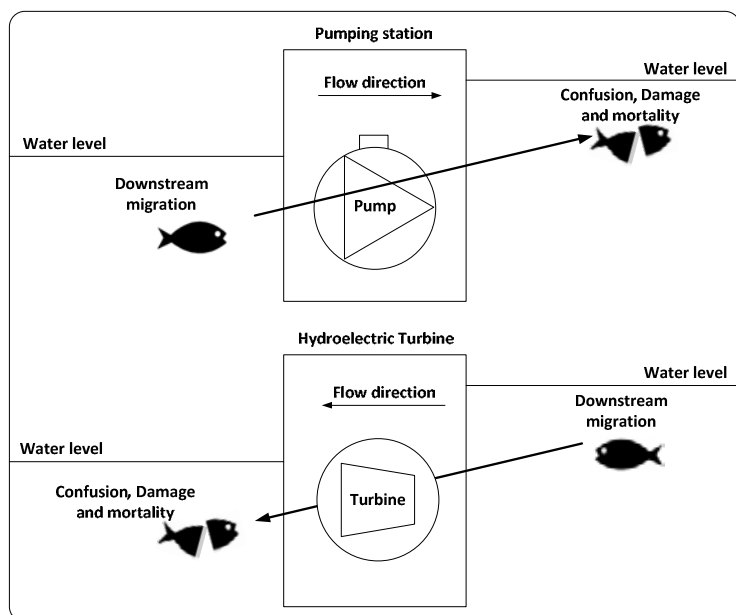


Figure 6: Hazards posed by pumping stations and turbines

the downstream migration of fish at pumps and turbines can occur due to impingement, entrainment or increased predation (Hadderingh, 1979; Therrien & Bourgeois, 2000; Larinier, 2001; Bruijs, 2004; Cada *et al.*, 2008; Turnpenny *et al.*, 1998; Gerompé *et al.*, 1994; FERC, 2001).

All of these studies focused on damage and mortality induced by impingement and suggest that axial screw pumps result in the largest amount of damage, followed by centrifugal pumps. These are pump types that occur most frequently in the Netherlands. Moreover, polder pumping stations are often characterized by their small size and high rotation speed which also enhances the injuries and mortality induced. Besides these technical aspect, species, size, life-stage, and physiological condition of the entrained fish also influence entrainment survival.

3.1.1. Impingement

Impingement occurs when a fish contacts a waste rack or waste which is present near the entrance of pumps or turbines. Fish can be forced against waste or waste racks, when they do not have the capacity to swim against the current present. Impingement can cause bruising, scale removal and other damages and finally lead to exhaustion and mortality when fish are forced into a pump or turbine or due to mortal damage (Acres International Corporation, 2005; Hadderingh, 2002).

3.1.2. Entrainment

Active or passive passage of fish, fish larvae or eggs through a turbine or pump is referred to as entrainment. Studies of fish damage and mortality at hydroelectric turbines and pumping stations have identified different origins of hazards for fish. Damage to fish is caused by collision with mechanical parts, by exposure to fluctuating pressures, by cavitation and by shearing damage (Turnpenny *et al.*, 1998; Gerompé *et al.*, 1994; Cada *et al.*, 2008; FERC, 2001).

Mechanical damage results from contact with fixed or moving equipment, and is a function of the characteristics of the turbine. Immediate damage largely depends on turbine or pump characteristics such as number of blades, revolutions per second, blade angle, runner diameter, hub diameter, and discharge height. Moreover, the size of the fish is also of influence to damage and mortality rates (Gerompé *et al.*, 1994; Bruijs, 2004). Models have been developed to estimate the number of fish of various size that will come into contact with the turbine machinery. Amongst others, these models



Figure 7: Damaged pike, bream, roach and eel collected at a Dutch & Belgium pumping stations (Source: D. Buysse, INBO, G. Kruitwagen, Witteveen + Bos, VisAdvies)

predict that fish size is positively correlated with the potential for physical strikes (Gerompé *et al.*, 1994; Deng *et al.*, 2005). Mechanical damage results in bruising, abrasion, cuts, decapitation or complete grinding of fish.

Within turbines and certain pumps pressure can drastically change as water moves through a turbine. These pressure changes that entrained fish experience are influenced by the turbine design, flow rate and the position of the fish in the water column prior to entrainment (Turnpenny *et al.*, 1998; Gerompé, 1994; Therrien & Bourgeois, 2000; FERC, 2001). At the intake pressure rises after which a region of sub atmospheric pressure occurs at the blades. Pressure quickly returns to atmospheric pressure in the draft tube and tail water. The amount of pressure damage may depend on the depth of the intake, net head, as well as the pressure tolerance and the acclimation pressure of the entrained fish species or life stage (Franke *et al.*, 1997). Benthic fish (bottom dwellers) are acclimated to relatively high pressures, while surface dwellers are accustomed to near atmospheric pressures. Physostomous species can quickly regulate the pressure in their swim bladder through an air canal which connects the swim bladder with the mouth, while physoclistic species can only slowly regulate the pressure of their swim bladder by gaseous exchange with blood vessels in the wall of the swim bladder. Physostomous species are therefore much less susceptible to swim bladder ruptures due to sudden pressure changes (Abernethy *et al.*, 2001). Table 2 (appendix 2) gives these swim bladder characteristics of polder fish species.

Cavitation results from regions of sub atmospheric pressure on the edges of blades. Water vapour bubbles are formed as pressure decreases to vapour pressure of water. These bubbles can collapse when they collide with regions of higher pressure, generating shock waves. Fish that pass such a region of collapse will be damaged or killed. Cavitation is an undesirable and costly condition both for operators and fish (Turnpenny 1998; Gerompé *et al.*, 1994; FERC, 2001). Internal injuries, such as eye bulging, hemorrhages, rupture of the swim bladder, and gaseous embolism, which are caused mainly by pressure variations and cavitation (Gerompé *et al.*, 1994).

Sudden flow velocity changes within turbines and pumps can induce turbulence. Turbulence can also create so-called shear forces that can tear fish to pieces. Turbulence and shear forces can also spin or distort a fish (Turnpenny *et al.*, 1998; Gerompé *et al.*, 1994; FERC, 2001; Abernethy *et al.*, 2001).

Delayed mortality, due to internal injuries, is mostly not accounted for in the studies. For diadromous species mortality rates can be even higher due to cumulative influence of pumping stations. These species often have to pass several pumping stations on their migratory route (Denayer & Belpaire, 1996; Winter *et al.*, 2007; Jansen *et al.*, 2008).

3.1.3. Predation

It appears that migrating species suffer increased predation in the vicinity of a turbine or pump, whether by other fish or birds. Besides their effects due to impingement and entrainment pumps and turbine can obstruct migrations due to their deterring entrance or the sound and vibrations they produce. This may result in an unnatural concentration of fish following from these migration delays upstream of a turbine or pump. Normal predation may become modified at locations with these unnatural concentrations of fish. Fish can also become more vulnerable to predators after turbine or pump passage, because of the above mentioned stress and disorientation. Entrances and exits are also good habitats for predators (Beijer, 2003).

3.2. Isolation and connectivity

The disruption of connectivity within and between polder and adjacent waters leads to fragmentation of habitats. Fragmentation affects the quantity and structure of habitats, both the extent and accessibility of habitats decreases, which can affect the quality of polder and reservoir canal systems for fish communities (Van Liefferinge *et al.*, 2004).

Pumping stations form an obstruction in both up and downstream directions. However, there are some differences between these two routes. Besides the difference in purpose of fish to migrate in each direction, the means in which pumping stations pose an obstruction also differs. Pumping stations obstruct migrations due to their deterring production of sound, vibrations or because fish are too large to pass through waste collection structures in downstream direction (Sand *et al.*, 2000; Beijer, 2003; EPRI, 1999). A physical obstruction is formed in upstream direction. Moreover, fish can enter polders in upstream direction through sluices or water inlet sluices, which are often available. Although alternative routes in upstream direction exist, one might argue that fish are attracted by the flow produced by pumping stations. This is supported by observations and by the attraction flow hypothesis. A fish passage with an attraction flow is commonly used to avoid turbine related damage for downstream migrating fish (Larinier, 2001; Lindmark & Gustavsson, 2008). Nevertheless, direct evidence that fish are attracted by this attraction flow is largely lacking (Larinier, 1998; Lucas & Baras, 2001; Winter, 2007). A behavioral study of ide (*Leuciscus idus*), a river dwelling cyprinid (rheophilic), found that passage success was related to this attraction flow (Winter, 2007). Most polder fish, however, prefer lentic conditions and knowledge about the effects of an attraction flow on these species is scarce.

3.3. Other impacts from pumping stations

Water levels are managed by pumping stations, most often with unnatural high levels during summer and low levels during winter. Seasonal fluctuations of water levels in polder ditches reservoir canals are not allowed (Coops, 2002).

Water level management can affect fish communities in different ways. Fish communities are directly affected by water depth. Shallow and inundated areas are important spawning habitats for some fish species, for example pike (De Laak & van Emmerik, 2006). Fish can be predated more easily by birds in shallow ditches. The accessibility of important habitats can decrease due to low water level or drying of ditches. For survival in winter it is important that depth is maintained. Fish communities are indirectly influenced by the effects of water level management on vegetation, temperature and oxygen levels (Nijboer, 2000; Evers *et al.*, 2007).

3.4. Effects on polder fish communities

Fish can be affected on different levels. Obviously individual fish are affected by the damage and mortality induced by pumps. Individual fish are also affected by habitat fragmentation when their migratory need cannot be fulfilled. Moreover, individual fish are affected by fragmentation when they cannot escape from predation, pollution, low oxygen levels or high temperatures (Van Liefferinge *et al.*, 2004).

Passage through pumps, although fatal to the individual, may have no impact at the population level since biological compensatory regulations might mitigate these losses. Population level impacts depend on the percentage of fish that entrain as well as the mortality induced by entrainment. The severity of the impact will depend on many aspects of the population biology of entrained fish species. The size of the population, the length, weight and age structure of the population, the reproductive potential of the population, and the natural survival rates (unrelated to entrainment) of the population. Migratory species are more likely to entrain in pumps, since these species need to pass these obstacles for their life cycle fulfillment (Cada *et al.*, 2008).

Habitat fragmentation can influence the biodiversity or productivity of fish populations, since populations cannot fulfil their lifecycle without access to specific habitats. This type of fragmentation especially affects species that need large territories for their lifecycle fulfillment, such as diadromous species (Van Liefferinge *et al.*, 2004; Lucas & Barras, 2001). Isolated water bodies are often inhabited by smaller fish and the absence of sufficient spawning habitats can decrease juvenile survival rates. Smaller populations can easily become extinct as soon as they cannot escape from accidental pollutions. The tolerance to low oxygen concentrations, high temperatures and pollution differs between species.

Hence, pumping stations might also affect populations of species, such as bream and pike, which need shallow water to spawn or deeper waters to hibernate during winter. The habitat size within a polder and the presence of spawning habitats and shelters are important variables influencing the effects of isolation on populations of these species (Van Liefferinge *et al.*, 2004; Lucas & Barras, 2001). For this reason, the enabling of fish migration between vegetation rich, shallow polder- and adjacent deeper water bodies is sometimes seen as a cost-effective measure when judged against the construction of required habitats in either of those systems (Riemersma & Kroes, 2004).

A barrier can also influence the exchange between, or expansion of different sub-populations. Small populations have a lower genetic diversity. Inbreeding and low genetic diversity enhance the changes for extinction of populations since the tolerance to environmental changes decreases (Hänfling and Brandl 1998). However, most polders are not completely isolated since water inlets and birds often introduce juveniles into a water system, in consequence the genetic variability might not necessarily be affected by polder pumping stations (Hänfling *et al.*, 2004).

Within a fish community species composition can be influenced. On the one hand diadromous species, species that need large areas for their lifecycle fulfillment and species with a low tolerance to fragmentation are more likely to decrease in numbers than other fish species. On the other hand some polder fish species, such as the bitterling and weatherfish, actually benefit from isolated circumstances. Hence, ordinary competition and predator-prey interactions can be influenced.

An complete ecosystem can be manipulated by fish immigration and emigration to and from a system. Most commonly addressed is fish induced sediment resuspension. This sediment resuspension instigates increases in the turbidity level of polder waters. A high turbidity level again restricts the development of both submerged and shore vegetation and other organisms that depend on these types of vegetation (Jeppesen *et al.* 2003; Kasprzak *et al.*, 2007). Although sediment resuspension is mostly associated with wave action in shallow lakes, the bottom-feeding activity of fish may also cause resuspension of sediment in polder systems. Benthivore fishes such as common carp (*Cyprinus carpio*) and bream ingest sediment, from which food particles are retained by filtering through gill rakes (Lammens & Hoogenboezem, 1991). The fine sediment particles that are not retained by fish become

suspended in the water. Given that these fish may process up to five times their body weight of sediment per day, the effect on turbidity can be considerable in waters with high fish densities (Meijer *et al.*, 1999; Lammens *et al.*, 2004; Jeppesen *et al.* 2003; Kasprzak *et al.*, 2007). Other fish induced ecosystem effects results from food web interactions within aquatic ecosystems. Planktivorous fish are known to influence the zooplankton biomass in aquatic ecosystems (Kasprzak *et al.*, 2007; Brodersen *et al.*, 2008). Zooplankton, such as the water flea (*Daphnia sp.*), are an important factor regulating phytoplankton biomasses within aquatic ecosystems. Large amounts of phytoplankton can again influence turbidity and oxygen concentrations in ecosystems (Kasprzak *et al.*, 2007; Brodersen *et al.*, 2008). Hence, immigration of benthivore and planktivorous fish species can increase the turbidity of- and hamper the biodiversity within polder waters and vice versa. For this reason, it might not always be desirable to enable fish migration towards polders.

Besides the im- and emigration of benthivore and planktivorous fish, isolation can also influence the presence and distribution of exotic species, such as grass carp (*Ctenopharyngodon idella*), asp (*Aspius aspius*) and nonindigenous crayfishes. Exotic species might threaten native fish populations or ecosystems, since they might alter habitats due to increased grazing of vegetation (Lodge *et al.*, 2000). Furthermore, introductions of exotic species might cause alterations in food web dynamics, introduce parasites and pathogens and cause a decrease in genetic variability due to hybridization with endemic species (Otburg & Higler, 2003; Crivelli, 1995). One might also argue that the fish mortality induced by pumping stations might influence the input of organic material into aquatic ecosystems.

4. Solutions for hazards and obstacles posed by pumping stations

This chapter concerns measures that are proposed to prevent or mitigate the hazards and obstacles provided by pumping stations. The restoration of fish migration between reservoir canals and polder water bodies concerns both lateral and longitudinal migration. The original dynamics of these waters has been lost due to land reclamations and water level management.

The available mitigation measures are dependent on the objectives set. There are differences in measures that can be taken to enhance the opportunities for migration or to prevent damage and mortality. Many solutions are available to facilitate upstream fish migration, especially for migratory fish in running waters (Kroes *et al.*, 2006). Downstream- and bidirectional fish passage technologies that prevent entanglement and enable passage of fish are much less advanced. This is partly due to the fact that efforts towards re-establishing free movement for migrating fish began with the construction of upstream fish passage facilities and that downstream migration problems have only more recently been addressed. Most hydraulic artefacts are more easily passable in downstream direction. This is also because the development of effective facilities for downstream migration is much more difficult and complex (EPRI, 2000; AIC, 2005; Cada, 2008).

4.1. Natural and semi natural

The best way to enable fish migration would be to remove pumping stations completely. In so doing, transitions between polders and reservoir canals are opened and fish can freely migrate between these waters. Natural seasonal water level dynamics is restored. These type of measures can be combined with opportunities for water storage (Kruitwagen, 2007; Kroes & Monden, 2005).

Since pumping stations fulfil an important role

Fisheries

An important factor influencing the effectiveness of the solutions for the hazards and obstacles posed by pumping stations is the ability of fishermen to fish in proximity of (fish friendly) pumping stations and bypasses. Solutions might not be very effective once fish which passed through are caught by fishermen at the discharge gates of these constructions.

The fishery law and regional water policies prohibits fishing in the vicinity of hydraulic artifacts and fish passes (LNV, 1999; Sportvisserij Nederland, 2007). Although fishing in the vicinity of (fish friendly) pumping stations and fish passes is most often not allowed, practices sometimes show otherwise.

No experience exist concerning fisheries at fish friendly pumping stations, since only one station is adapted up till present in The Netherlands. As mentioned above pumping station can be compared with hydropower turbines and cooling water intakes. An example of a fishery operating at a cooling water facility does exist. The Bergumer central in Friesland is a power station, which uses water from the Bergumer lake for cooling. Entrained fish is removed from this cooling water by circular filter panel which transport fish through a canal to a discharge end. Initially the discharge end was located in the lake were a fisherman placed its fykes in front of the discharge end. The discharge pipe has been placed elsewhere to prevent this. However, the fisherman litigated the energy company for loss of income and won. Resulting in a situation where he can still place his fykes at the discharge gate. Efforts to prevent fish damage or to direct fish back to the lake at this cooling water facility would therefore be completely ineffective (Westerbeek, 2005).

in drainage control for human safety, agriculture and infrastructure, this is most often not a possible option. Opportunities for the removal of pumping stations are only created, when realizing nature and water storage areas (Kroes *et al.*, 2006; Kroes & Monden, 2005).

4.2. Technical

More applicable, technical solutions exist as well. Some of these can solve both problems related to pumping stations; The obstruction caused for up- and downstream migrating fish and the hazard caused for downstream migrating fish. In order to create a truly fish friendly pumping station, both the obstruction and the hazard posed by a pumping station should be diminished. Since some of the solutions facilities are not passable in two directions, a combination of solutions might be appropriate.

4.2.1. Bypasses

Commonly used measures at hydraulic obstructions are so-called bypasses, often referred to as fishways, fish ladders or fish passes. Examples of such measures that can (theoretically) be utilized at pumping stations are pool fishways with overfall weirs, basin passages with a V-shaped overflows, vertical slot passages and De Wit passages (Kroes & Monden, 2005; FAO & DVWK, 2002; Larnier, 2001; Heuts, 2005). Their general principle is similar (indicated in figure 8); the original height difference will be divided over a number of steps, each step is separated by a structure with an overflow, underwater opening or combination of those, in order to reduce the stream velocity. This way the fish can regain their strength to overcome the next step and pass the barrier. These structures differ mutually, due to water flow rates within the passage, bottom and surface passability, water losses, effects of changing water levels on the water levels within the pass, sensitivity to wastes and the lure stream which is produced (Kroes & Monden, 2005).

Other examples of bypass systems are fish sluiceways or locks and eel gutters. A fish sluice works with the same principle as a canal lock, figure 8 indicates the different stages of this principle. Fish are lured to a compartment by a water stream and when this compartment is filled a sluice door will open and fish can pass to the other side. This passage has the disadvantage of not providing a continuous passageway. An eel gutter is primarily designed for elver (young eel) which are able to crawl or climb over an obstacle. In the gutter a material, usually synthetic grass or brushes, which reduces the water velocity is utilized. This passage is easily built into existing constructions (Kroes & Monden, 2005).

Even though numerous types of bypasses are available, opportunities are limited in polder areas. Firstly, because water management within polder areas is focused on the submission of water and water losses are inevitable when bypasses are used. Second, because it is naturally impossible to migrate upstream from a higher to lower water levels and vice versa. In natural situations the upstream habitat is located higher than the downstream area. Most of the Dutch polder areas are located below sea-level, which causes problems for fish that need an attraction flow to orientate towards their 'upstream' habitat. This also implies that a artificial attraction flow has to be created. Since these passes have not been utilized widely to provide passage at pumping stations, the effectiveness of these passes at locations with unnatural water levels remains unknown.

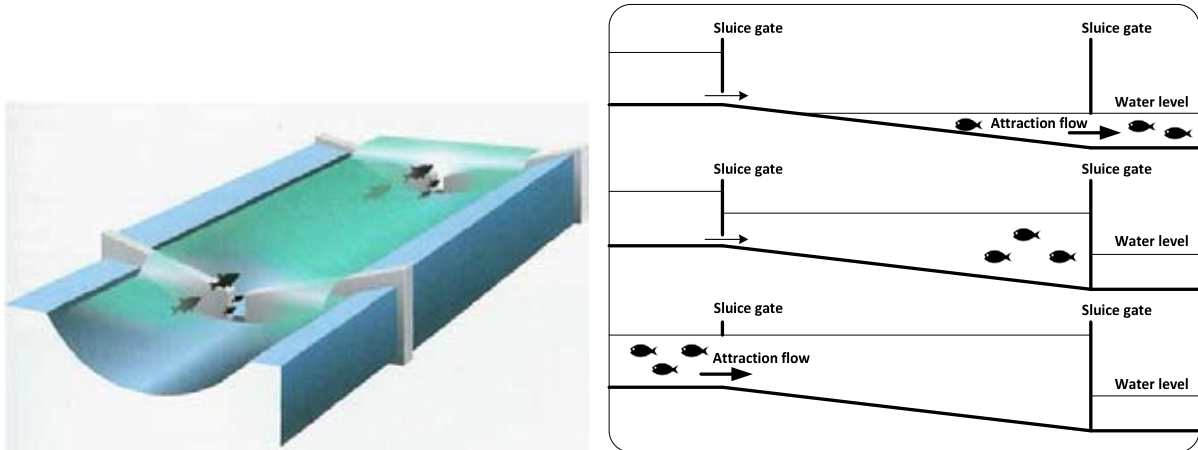


Figure 8: Illustrations of a combination of a V-shaped and vertical slot fish passage and a (fish) sluiceway
Source: Kroes & Monden, 2005

4.2.2. Bypasses with pumps

To overcome the problem of upstream migration from higher to lower water levels bypasses with pumping mechanisms, such as a siphon passage, eel siphon, Fishflow siphon fish ladder, Manshanden fish-friendly pumping station or an Archimedes screw passage can be used (Kroes & Monden, 2005; RWS Limburg & Fishflow Innovations, 2008; Brenninkmeijer *et al.*, 2005). Bypasses mentioned in 4.2.1. can also be adapted with a pumping mechanism to create a lure stream and a “natural flow direction” (Schreuders *et al.*, 2008). An example of such a bypass, that is build at Abelstok pumping station in Groningen is shown in figure 9.

The exact pumping mechanism of these solutions differs, though they all pump water from the ‘upstream’ habitat into a higher area (reservoir canal) as a means to generate an attraction flow. Moreover a natural flow direction is provided within the pass. In a siphon passage and eel siphon water is pumped through a compartment wherein fish might assemble since they are attracted by a lure stream (Kroes *et al.*, 2006; Kroes & Monden, 2005; RWS Limburg & Fishflow Innovations, 2008; Brenninkmeijer *et al.*, 2005). After a certain period of time the compartment is closed and all the air is pumped out of the siphon tube, causing the water with the fish to be siphoned to the lower area. A siphon utilizes a vacuum pump to transports the fish to the low lying polder area. The Archimedes screw pump works similarly, though utilizes a Archimedes screw to pump water to the collection compartment which is located on a higher level than the reservoir canal and the water with the fish are transported by gravitational discharge. The Archimedes screw can also enable fish migration in downstream direction. In order to migrate in this direction fish can pass along this screw. Although this screw provides a route in downstream direction, it might still damage or deter fish. When upstream migration is considered, both the Archimedes screw passage and siphons have the disadvantage that continued passage is not possible (Kroes & Monden, 2005). The Manshanden passage for pumping stations does not work with a so-called assembling compartment which closes periodically and therefore provides a continual flow through the passage (Kruitwagen *et al.*, 2006). Drawbacks of most of these constructions are that they require relatively more maintenance than other technical solutions, that passage is only enabled when they operate and that they are not applicable at large height differences.

Little is known about the affectivity of these measures at pumping stations. Some of these bypasses have proven to be effective at weirs (Schreuders *et al.*, 2008; Bakker, 2008). Siphons are effectively utilized to promote upstream elver migration at larger pumping stations along the coastline (Brenninkmeijer *et al.*, 2005). The Manshanden passage for pumping stations has been effectively utilized at a polder pumping station. Monitoring results at this bypass showed that many different species were able to pass without damage (Kruitwagen *et al.*, 2006).

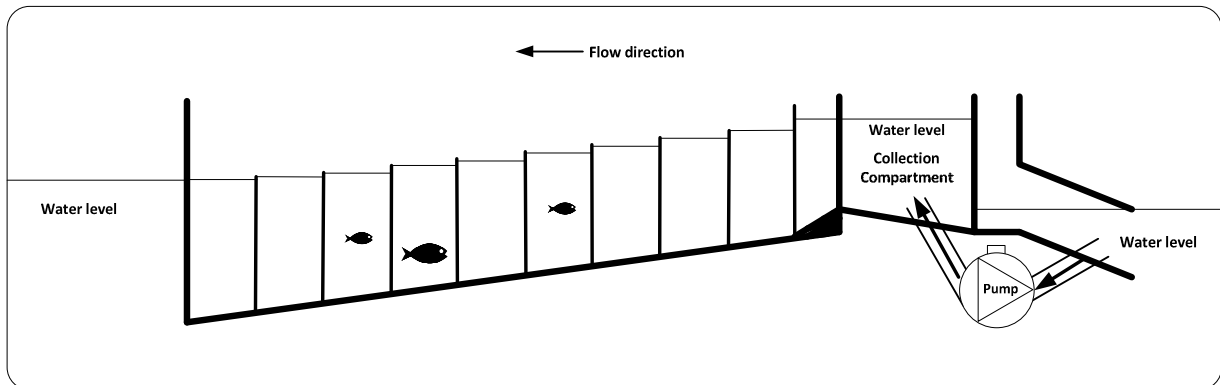


Figure 9: Cross section of an de Wit passage with a pumping mechanism
Source: Schreuders *et al.*, 2008

4.2.3. Screens/ barriers

Mechanical and behavioral mechanisms can be used to prevent fish entrainment. Examples are physical barriers such as waste racks, screens and behavioral barriers, such as strobe lights, sound, vibrations, electric barriers and bubble screens. Fish protection systems of which the functioning is based on physical blocking are found to be more effective than those fish protection systems of which the functioning is based on the behavior of fish (Beijer, 2003; Bruijs, 2004; EPRI, 1999). Though this greatly depends on the availability of alternative migratory routes and the fish species considered (Kroes *et al.*, 2006).

Many of the mechanical systems are very prone to wastes. Clogging of wastes against screens enhances the flow velocity resulting in a decrease in functioning, since impingement becomes more likely. The maintenance of these type of structures, with motorized waste collector cleaners, is therefore very expensive (EPRI 1994; Bruijs, 2004).

4.2.4. Fish-friendly pumps

In certain pumps, often referred to as fish friendly pumps, pumps are adapted as such that fish can pass without damage. At present several pump types are claimed to be fish friendly, but it remains unknown if these claims are legitimate.

Pumps that claim to be fish-friendly are the De Wit adapted Archimedes screw, Hidrostral pumps, the Fishflow screw pump and the adapted fan for axial flow pumps (Kruitwagen & Klinge, 2007; Landustrie, 2008; Helfrich *et al.*, 2004). Hidrostral pumps date back to the 1960 when Martin Stähle invented the screw centrifugal impeller specifically to offload fish from trawlers. Conventional Archimedes screws and Hidrostral (helical) pumps are already widely utilized in Dutch pumping stations.

The other pumps specified above are specifically designed to enable fish passage. The design of fish friendly pumps is as such that their blades are less likely to damage fish.

The first windings of the De Wit Archimedes screw are adjusted as such that their edges are curved, as a result the blades will move more smoothly into the water. The Hidrostral pump is accommodated with a screw which can be compared to a corkscrew. The width of its blade gradually increases in radial direction. In a FishFlow screw pump the blades are adapted as such that the width of the blades gradually decreases from the middle outwards during the last few windings until the blades ultimately merge with the housing of the screw. This pump is also provided with a casing that rotates together with the screw in order to prevent fish from getting trapped between the blades and the casing. This pump also claims to produce little deterring sound. Most of these designs are less prone to wastes than other pumps as well (McNabb *et al.*, 2000; Helfrich, Bark, Liston, Weigmann &, Mefford, 2004).

Little research has been performed on the effectiveness of these pumps. Some efforts did show that Hidrostral pumps, De Wit screws and Archimedes screws can provide a safe passageway, however pump size and speed can affect fish survival (Kruitwagen & Klinge, 2007; McNabb *et al.*, 2003, Helfrich *et al.*, 2004). As described above, pumping stations can create a delay in, or completely obstruction fish migration in downstream direction, since fish might be deterred by sound and vibration or too large to pass through waste collection structures (De Lange & Merx, 2005; Merx & Vriese, 2006; Kroes & Monden, 2005). The effectiveness of these fish friendly pumps will therefore not only depend on their ability to enable safe fish passage, but also on the willingness of fish to pass through these pumps. Moreover, waste collection structures also need to be adapted to enable fish passage. Another factor



Figure 10: De Wit adjusted Archimedes screw

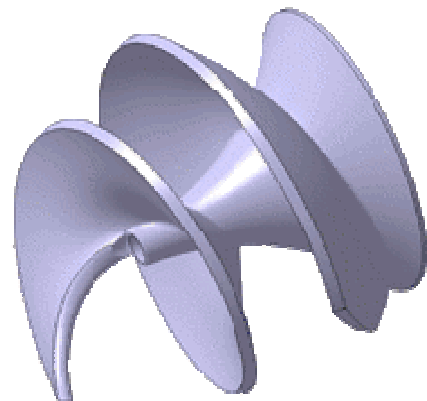


Figure 11: Hidrostral screw

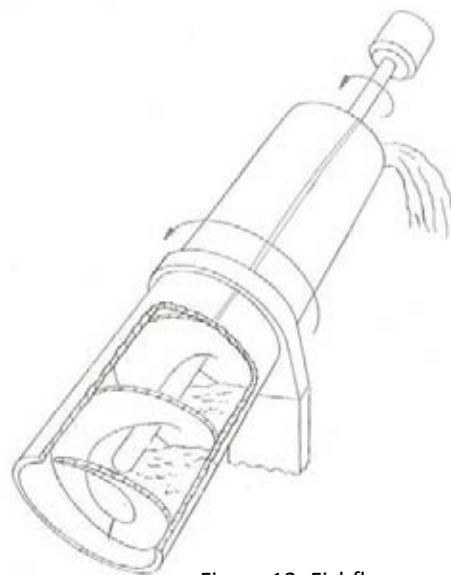


Figure 12: Fishflow screw pump

which needs to be taken into consideration when fish friendly pumps are utilized is that downstream migration is only enabled when the pump is operating and Dutch pumping stations do not operate during 60-80% of time (Kunst *et al.*, 2008). Even if these pumps prove to be passable in downstream direction, they still pose a barrier in upstream direction. Structures that work similarly as the Archimedes screw passage described above, can be utilized to enable two sided passage.

4.3. Adjusted management

Management of both pumps and/ or inlet structures can be adjusted in order to prevent damage to fish or to enable fish migration.

4.3.1. Adjusting management to prevent damage

In order to minimize damage when fish pass through a pump, pumps can be managed differently. The rotation speed of pumps can be lowered, if the pump capacity is high enough to transport water over a certain head. The number of pumps utilized within a single pumping station can be increased, since this results in a decrease in suction force (Marmulla, 2001; Kroes & Monden, 2005).

4.3.2. Adjusting management to enable migration

The management of water inlet sluices and canal locks can also be adjusted to enable fish migration. Sluices or locks in the vicinity of a pumping station are preferred, because an attraction flow is produced by the pump. In order to give fish opportunities to migrate through discharge gates it is essential to open gates with a minimal height difference. This will reduce the water velocity and give the fish a longer period of time to migrate. The entrance location, adequate flow, and thorough maintenance and debris removal are critical factors to success (Kroes & Monden, 2005; EPRI, 1999; FERC, 2001). Problems associated with sluices and locks in polders are similar as those of bypass facilities. Besides the absence of an attraction flow for upstream migrating fish, the flow direction through polder sluices will be opposite to the flow direction which is expected in a “natural situation”.

5. Society & legislation

This chapter concerns the societal and legislative wishes and demands with regard to fish migration. The first paragraph gives a general description of all actors involved and concerns the responsibilities and authorities of water boards. The last paragraphs concern the societal situation and the laws and legislations concerning fish protection and fish stock management.

5.1. Actors, responsibility and authority

Water boards are regional governments which are responsible for water barriers, qualitative and quantitative water management within certain regions. These regions have different borders than provinces, since their determination is based on natural borders of catchment areas. Water boards are the oldest democratic institutes in The Netherlands (UVW, 2007). The European Union, the national government and provinces provide frameworks for regional water policy and management. These governments define policies and legislation for fish stocks, while water boards implement and translate these policies and legislations (UVW *et al.*, 2006).

Both quantitative and qualitative water management can manipulate fish habitats and therefore the composition of fish stocks. On the other hand, fish stocks can influence water quality. Hence, all measures concerning fish habitats and those that focus on objectives set for fish stocks and the ecological functioning of water systems are incorporated in fish stock management. Fisheries management encompasses all measures in relation to professional and recreational fisheries. Actors involved in fish stock and fisheries management are represented in a Fish stock management commission (VBC). Within such a commission, provinces, fisheries, nature organizations and water managers cooperate to unite fish stock management and fisheries management. However, water management has the final authority within fish stock management (UVW *et al.*, 2006).

5.2. Animal wellbeing; ethics

The wellbeing of a fish or population of fish depends on their ability to maintain their physical condition and avoid suffering. Some degree of stress is inevitable within the lifespan of any conscious animal and is a form of education for survival of an individual and fitness of the species. Animals suffer when they fail to cope with stresses because they are too severe or too prolonged (Schrekenbach, 2008). A controversy in discussions about animal suffering is whether animals exposed to stresses such as physical injury experience what humans would call suffering.

The neocortex is a part of the brain of all mammals and is an important part of the neural mechanism that generates the subjective experience of suffering. It has been argued that the absence of a neocortex in fish indicates that fish cannot suffer. However, recent studies found that complex animals with sophisticated behaviours, such as fish, probably have the capacity for suffering. Consequently, injuries caused by pumps negatively affect the wellbeing of individual fish. Moreover, studies have also shown that fish can experience fear-like states and that they avoid situations in which they have experienced adverse conditions, such as passage through a pumping stations (Brown & Laland, 2003; Iwama, 2007; Schrekenbach, 2008).

Although these scientific studies consider animal suffering, concerns about anthropogenic influences on the wellbeing of fish are primarily grounded within the values of the general public. In the Netherlands, public attention for animal wellbeing is growing (Werkman, Valk & Leineweber, 2007). Hence, attention for the wellbeing of fish as well, especially since fish are larger aquatic animals that are more visible than other aquatic organisms. Nevertheless, the problems that fish can encounter at pumping stations are often not visible and therefore remain largely unacknowledged.

The growing public attention for animal welfare is partially reflected with the rising of the Party for the Animals. Together with the Dutch foundation for the protection of fish (Stichting Vissenbescherming) and the Clear Water Foundation (Stichting Reinwater), this party expresses its concerns about the damage and mortality occurring at pumping stations (Partij voor de Dieren, 2008; Hendrikse, 2007; Vissenbescherming, 2008). This attention is also reflected in the definition of governmental policies. A policy act on animal wellbeing has recently come into force (LNV, 2007). This bill, however, only concerns domesticated animals and humane ways to kill animals that are used for consumption. The general duty to care for all native flora and fauna which is prescribed by the Flora and Fauna law (explained below) also inquires attention for the intrinsic value of non domesticated, native fishes (LNV, 2002). As pumping stations can pose a hazard to native fishes, this general duty results in the obligation to create “fish-survivable” pumping stations, if this can be fairly required. The question whether the creation of fish-survivable pumping stations can be fairly required is dependent of the cost-effectiveness of measures that can create such pumping stations. Offence of this general duty is not liable to be punished, but will be considered when other felonies are judged.

5.3. Species protection

Habitat & Bird Directives

The Habitat Directive concerns the preservation of natural habitats of wild flora and fauna. This Directive aims to establish a ‘favourable conservation status’ for specific habitat types and species that are selected as being of EU interest. The Birds Directive concerns the conservation of wild birds (European Commission, 1979; 1992). Together these directives constitute the backbone of European policy on biodiversity protection. A vast number of protected areas, known as the Natura 2000 network, have been established throughout Europe. The Habitat and Birds Directives are accommodated in national legislation in the Netherlands as well. The Flora and Fauna law concerns the protection and preservation of species and the environmental protection law concerns the protection of natural habitats (LNV, 2002).

The Flora and Fauna law aims to protect and preserve specifically indicated plant- and animal species (listed in Annex II³ and IV⁴ of the Habitat Directive). This implies that all activities which negatively affect these species are prohibited. Different levels of protection exist for specifically listed species. Moreover, animals that are not of direct use to humans are also acknowledge for their intrinsic value as explained above.

³ Annex II: Animal and plant species of community interest whose conservation requires the designation of special areas of conservation

⁴ Annex IV: Animal and plant species of community interest in need of strict protection

For the implementation of projects that can negatively affect protected species, a dispensation needs to be requested at the ministry of agriculture, nature and food quality. A project found to have a negative impact on protected species may nevertheless be carried out if there are no alternative solutions or imperative reasons of overriding public interest. Furthermore, these project are only allowed when mitigating or compensatory measures are taken. A so-called behavioral code for water boards allows a dispensation for many activities of water boards (UVW, 2006).

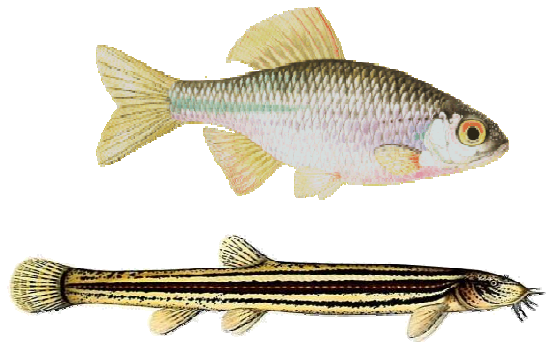


Figure 13: The bitterling and weatherfish

Fish species that typically occur in polder water bodies and are protected under the Dutch Flora and fauna law are the bitterling, the weatherfish (*Misgurnus Fossilis*) and the spined loach (*Cobitis taena*)(LNV, 2002). For the bitterling and the weatherfish the highest level of protection is applicable, while for the spined loach a lower level of protection is applicable. For the construction of pumping stations a dispensation only needs to be requested, if this would affect the bitterling or weatherfish. An exemption from the behavioural code applies for the spined loach, since a lower level of protection is applicable for this species. If the operation of pumping stations would negatively affect the bitterling, the weatherfish or the spined loach a dispensation always needs to be requested. A dispensation is granted when the operation of pumping stations would negatively affect individual fish, but does not significantly affect fish populations. Pumping stations have to be made “fish-survivable” when a dispensation is not granted.

The Birds Directive is also accommodated under the Flora and Fauna law and Natura 2000 sites in the Netherlands. Since fish are an important food source for birds, birds can be affected by degrading fish stocks. Hence, the construction or renovation of pumping stations can indirectly affect protected bird species. Shallow polder waters are important foraging areas for the under the flora and fauna law protected common spoonbill (*Platalea leucorodia*), the grey heron (*Ardea cinerea*), the great crested grebe (*Podiceps cristatus*), the great cormorant (*Phalacrocorax carbo*), the common merganser (*Mergus merganser*) and the smew (*Mergellus albellus*). Especially the common spoonbill is an important species targeted for at fish rehabilitation projects (Brenninkmeijer *et al.*, 2005). In shallow polder waters, three spined stickleback (*Gasterosteus aculaetus*) is the main feed source for these birds.

Eel Regulation

The European Eel Regulation aims for a recovery of the European eel stock. It states that all member states need to develop a Community Action Plan for the Management of European eel, before the end of 2008. This action plan should include the current status, trends and targets for eels stocks and the measures to reach, and monitoring programs to validate the targets



Figure 14: European eel (*Anguilla anguilla*)

set. The measures proposed need to reduce the anthropogenic mortality of eels to ensure that at least 40% of the pristine eel population biomass can escape to sea.

When community action plan is not developed by a member state or approved by the European Commission, member states need to ensure a reduction in eel catches by at least 50 % relative to the average catch from 2004 to 2006, or take other measures with an equivalent result.

Measures proposed may contain the reduction of fishing effort, restocking measures, the restoration of connectivity and the removal of predators. Non-fishery measures must be included, unless these are not necessary to attain the target (European Commission, 2007). Measures to mitigate the hazard and obstacles posed by pumping stations or the removal of pumping stations are possible measures that can be proposed for the restoration of eel stocks.

5.4. Sustainable fish stocks

Benelux decision free fish migration

In 1996 the Benelux Economic Union imposed that free fish migration need to be enabled in all catchments of the Benelux in 2010. The Netherlands signed the Benelux decision in 1996. The decision states that all member states need to develop and implement programs to enable free fish migration before January 2010. The facilitation of migration of larger diadromous fish has highest priority.

In contrast to Belgium the decision has never been integrated into Dutch legislation. Currently a revision of the decision for the integration in the Netherlands is made, since the original aims for 2010 are thought not to be feasible. The foundation for this alteration lays within the above mentioned prioritization of bottlenecks for fish migration (Kroes *et al.*, 2008). Besides this ecological based prioritization of hydraulic artifacts, the decision also states that mitigation measures have priority at newly constructed or renovated pumping stations (Benelux economical union, 1996). Measures to mitigate the obstacles posed by pumping stations or the removal of pumping stations are necessary to reach the objectives of the Benelux decision.

The Dutch Ministry of Transport, Public Works and Water Management formulated the so-called December bill in 2006 (V&W, 2006). In 2007 another letter of this ministries' minister of state was written in response to parliament questions (V&W, 2007). Within both documents several policy statements, which concern the Benelux decision and the European Eel Regulation, are made. This ministry states that water managers need to prioritize the bottlenecks for fish migration within their managed area and that measures to enable fish migration must, in any case, be implemented when pumping stations are constructed or renovated.

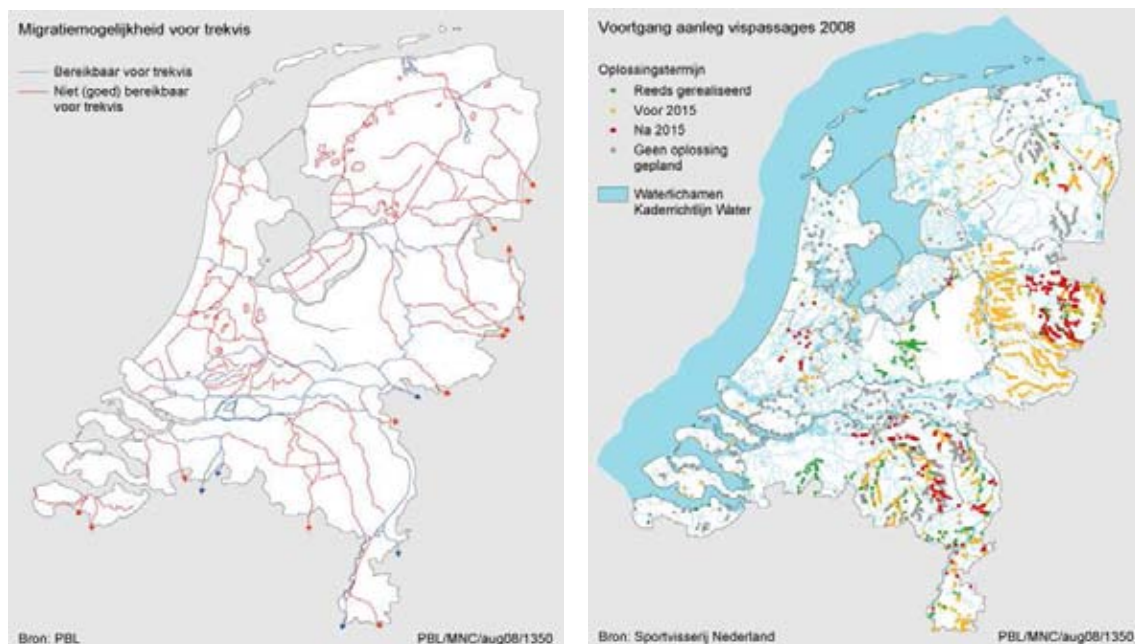


Figure 15: Migratory opportunities for fish in The Netherlands (blue lines indicate accessible locations, red lines indicate inaccessible locations) & Progress in the construction of fish passes (green dots indicate passes are present, orange dots indicate passes will be constructed before 2015, red dots indicate passes will be constructed after 2015, grey dots indicate no solutions are planned)

Water Framework Directive

In the year 2000 the European Water Framework Directive (WFD) was issued, strongly emphasizing sound ecological management of water in its Member States. The goal of this directive is to ensure that the quality of all surface- and groundwater in Europe reaches a high standard (good status) by the year 2015. Fish stocks are one of the 'biological quality elements' within this framework. The WFD is valid for all member states of the European Union, although member states have certain autonomy to determine how the WFD is integrated in their national legislation.

The WFD states that ecological monitoring programs have to be developed and implemented in 2006. In 2009 so-called River Basin Management Plans have to be implemented. These plans comprise the objectives set for each water body and programs of measures to meet those objectives. The objectives for each basin should be attained by in 2015 (European Commission, 2000).

Within these River Basement Action plans, water bodies are categorized into different types and for each type a 'natural' or reference condition should be used as the basis for determining a Good Ecological Status (GES). Most Dutch surface water bodies are created or heavily modified by humans and it would be unrealistic to base the determination of ecological objectives on a natural reference. For these heavily modified and artificial water bodies regional authorities must define both the highest achievable ecological status (Maximum Ecological Potential or MEP) and the ecological status they are actually striving to achieve (Good Ecological Potential or GEP). For a number of common types of heavily modified and artificial water bodies, national MEPs and GEPs (defaults) have been established to serve as examples. The MEPs for polder ditches and canals are derived from a best site approach, expert

judgment and the mitigation measures that can be taken to restore this ecological potential (Evers *et al.*, 2007).

The indicator used for the 'biological quality element' fish in ditches and canals are the species composition and abundance, since these assess the functional structure of a community. Common fish species are important indicators in the WFD, since the knowledge of these species is ample and they can indicate the functioning of the system accurately.

Measures to mitigate the hazard and obstacles posed by pumping stations or the removal of pumping stations are proposed as important measures to reach the objectives for the 'biological quality element' fish (Kroes *et al.*, 2008).

Ecological Network (Ecologische Hoofd Structuur, EHS)

The Dutch National Ecological Network (EHS) is a strategy to conserve biodiversity in a highly fragmented landscape, which is under heavy pressure of increasing economy and growth of human population. The EHS is a means to enlarge and connect nature reserves. The aim is to realize 728,500 hectares of nature by 2018. In addition, the network comprises more than 6 million hectares of water, including the Wadden Sea and the IJsselmeer.

Each EHS area has so-called nature target types, that are different types of nature which are aimed for in the Netherlands. These nature target types are specified in the aquatic supplement, that includes a detailed description of different types of water. For each nature target type, accompanying animal and plant species, habitats and management practices are described. An EHS status guarantees the protection and preservation of flora and fauna within an area. Within an EHS area anthropogenic operations are not allowed, unless there are no realistic alternatives and they are justified for public interest reasons such as public health, consumer protection or road safety. The EHS covers some polder water bodies and reservoir canals (Nijboer, 2000). Nature types corresponding to polder water bodies and reservoir canals are: Buffered ditches (nature target type 3.15), wide and narrow canals (nature target type 3.19).



Figure 16: EHS areas

One of the objectives set for these nature target types is that all physical barriers present that obstruct fish migration should be abolished in 2020. If pumping stations are present within EHS areas, these must be removed or when these pumping stations are considered justified for public interest, a 'realistic alternative' for this anthropogenic operation has to be utilized. Such a realistic alternative would be to implement measures that mitigate the hazard and obstacles posed by pumping stations.

6. Water management; Principles, Practices and Outcomes

The results of the interviews are described in this chapter. The same protocol was followed in each interview. Summarized interview sections are presented in table 4 and 5 (appendix 3). All respondents agreed with a written summation of their answers. As explained in the methodology ecologists with knowledge about fish migration were chosen as respondents of water boards. Their exact function denomination and perceived influence in their boards' fish mortality and migration policy is summarized in the table below.

Table 1, Interviewed respondents name, organization, function and influence in fish stock management

| Name | Water board | Function | Influence |
|--------------------------------|---------------------------------|--------------------------------------|-----------|
| Dwight de Vries | Reest en Wieden | Ecologist | Yes |
| Gerrit Jan van Dijk | Groot Salland | Ecology employee | Yes |
| Hanneke Maandag | Hollandse Delta | Water quality and ecology consultant | Limited |
| Hans Roodzand | Hollands Noorderkwartier | Water quality and ecology consultant | Yes |
| Harald Smeets (Marjoke Muller) | Rivierenland | Ecology and water quality employee | Yes |
| Helen Hangelbroek | Delfland | Water quality policy consultant | Yes |
| Iwan de Vries | Velt en Vecht | Ecology employee | Yes |
| Jacques van Alphen | Waternet/ Amstel, Gooi en Vecht | Water management consultant | Yes |
| Jappie van den Bergs | Fryslân | Senior planner | Yes |
| Jeffrey Samuels | Brabantse Delta | Ecologist | Limited |
| Lucienne Vuister | Rijnland | Ecological policy consultant | Yes |
| Marrit Meier | Schieland en de Krimpenerwaard | Policy consultant | Yes |
| Peter Heuts | De Stichtse Rijnlanden | Aquatic ecologist, Biology employee | Yes |
| Rob Gerritsen | Vallei en Eem | Senior aquatic ecologist | Yes |
| Wim de Wit | De Stichtse Rijnlanden | Project leader/ Technical innovator | Limited |
| Wouter Quist | Zeeuwsche Eilanden | Aquatic ecotechnologist | Yes |

6.1. Principles

In this section respondents were asked questions to assess their awareness and approval of hazards and obstacles posed by pumping stations. Within this section respondents defined problems fish might encounter at pumping stations and specific species or systems that are affected. Besides questions concerning ecological consequences, respondents were asked if economic and social consequences result from hazards and obstacles posed by pumping stations and if a distinction can be made in the actors (fisheries, governmental organizations, recreation, human settlements) that might be affected. Furthermore, the opinion of respondents about existing, and compliance with, legislative obligations to take actions was requested.

6.1.1. Internal; motivation

Respondents based their opinion about the ecological consequences of pumping stations on literature, expert judgement, monitoring and field experience. Little research and monitoring has been performed at pumping stations. Nevertheless, several respondents declared that pump operators (and fishermen) have seen fish clustering in front of, or die at pumping stations. Some water boards have also monitored this mortality and fish recruitment in front of their pumping stations.

Interview respondents were asked to grade the ecological, economical and social consequences of pumping stations. The results can be found in table 4 (appendix 3) and in figure 10. All agreed that fish encounter problems at pumping stations, because they are damaged or

obstructed. It has been mentioned frequently that the problems encountered by fish depend on the type of pump that they pass and on the fish species considered. Two respondents claimed that for this reason a grade for problems encountered by fish could not be specified.

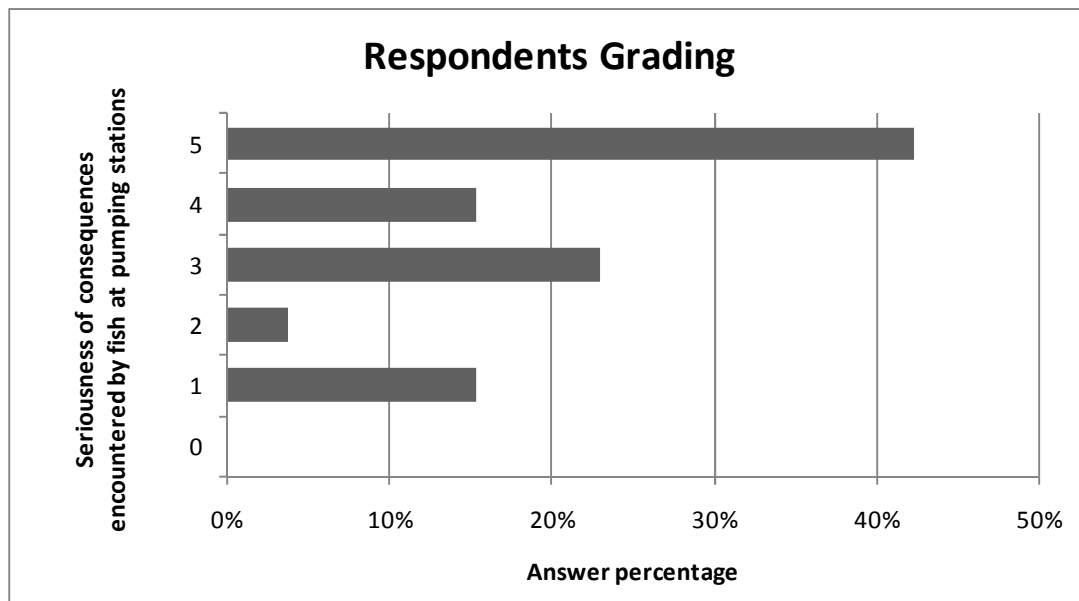


Figure 10: Respondents grading of problems fish might encounter at pumping stations; A zero indicates that respondents do not believe that pumping stations affect fish, a five indicates that respondents believe that these effects are very serious

Fish length is mentioned as an important factor influencing the effects of pumps; larger fish are more likely to be damaged by pumps. A few respondents stated that whole length classes of fish can be absent within their polders, which might result in similar effects as those resulting from the overexploitation of marine fish stocks. This exploitation by fisheries also resulted removal of larger fish. In consequence fish age and length at maturity decreased worldwide.

Migratory species such as eel and three spined stickleback were mentioned most frequently as being seriously affected by pumping stations. The given reasons for this were that cumulative effects can occur because these species can come across multiple pumps along their migratory route and, that these species need to migrate for their lifecycle fulfilment. Some respondents also mentioned that other species benefit from the ability to migrate for spawning in spring or hibernation during winter.

All respondents agree that differences exist in the problems encountered on the up- and downstream route; downstream passage through pumping stations can cause damage and mortality, while pumping stations obstruct migration in the opposite direction. Several respondents claimed that their larger reservoir stations mainly pose a problem for upstream migration, while polder pumping stations pose a large problem for downstream migration. Some research conducted at reservoir stations indicates that larger pumps instigate little damage, but do pose an obstruction for upstream migrating elver. In polder systems inlet sluices can often provide a passageway for upstream passage, while smaller (polder) pumps are extremely damaging for fish. It should be noted that the utilization of inlet sluices for upstream migration was disputed amongst respondents, due to the fact that these do not provide a continuous passageway and that the flow direction through these sluices is opposite to a natural flow direction.

Disagreement exists in respondents opinions about the scale of this problem, which is also illustrated by their grading shown in figure 10. Some respondents presume that pumps mainly affect individual fish, while others believe that pumping stations can also affect entire fish populations. Furthermore, a few respondents mentioned that pumping stations could even influence the water quality as a whole, due to cascading effects of altered fish communities (an explanation is given in paragraph 3.4). Fish populations that are considered likely to be affected are populations of migratory species and populations with large adults, for similar reasons as those mentioned above. Although many respondents agreed on the vulnerability of migratory species, some disagreement exists about the effects of pumping stations on three spined stickleback. One respondent stated that; “Three spined stickleback might be affected on a population scale, since this species is very dependent on the coastal zone”, while another stated that; “I do not believe that three spined stickleback is affected on an population scale, since this species can also survive within fresh water systems”.

Most respondents claimed that the hazards and obstacle posed by pumping stations do not provide large economical consequences for fisheries, human settlements or water boards. Professional fisheries are thought to be predominantly affected compared to other propounded actors. The main reason mentioned for this is the declining eel stock. Eel is one of the few, and the most profitable species which is professionally fished within fresh water systems. Nevertheless, it was frequently mentioned that fisheries are most probably a much larger cause of the declining eel stocks than pumping stations. It has also been pointed out that the cost of measures proposed for the Water Framework Directive and the fact that pumps can be jammed by eels might provide economical consequences for water boards.

Although the hazards and obstacles posed by pumping stations are thought to provide social consequences for different actors, these consequences are also believed to be generally unacknowledged. Especially recreational fisheries are considered to seriously resist the hazards and obstacle posed by pumping stations. 11 out of 15 respondents stated that water boards resist the hazards and obstacles posed by pumping stations. However, it was frequently mentioned that there are internal conflicts within water boards; technicians and pump managers often consider the utilization of proven techniques as more important than the choice for a fish friendly pump. Many respondents also stated that the problems which fish might encounter at pumping stations are often not observed by the average citizen, even though attention for animal wellbeing is growing. Moreover, one respondent also assured that farmers mainly care about the management of water quantity and that they are therefore not concerned with the hazards and obstacles posed by pumping stations. 9 respondents declared that large resistance, against hazards and obstacles posed by pumping stations, exist within nature conservation and animal protection organizations, animal activists and the political Party for the Animals.

6.1.2. Obligations

Most of the legislations explained in chapter 5 were mentioned by respondents. However, not all respondents were familiar with all of them. Most interviewed respondents stated that the European Eel Regulation and the Benelux decision are the most applicable legislations with regard to the hazards and obstacle posed by pumping stations. All respondents mentioned the Water Framework Directive, though some stated that this directive is not directly applicable to hazard and obstacle posed by pumping stations. The Flora and Fauna law has also been mentioned frequently. This law

has been mentioned for two reasons. Firstly, because it dictates a duty to care for all native flora and fauna and therefore also for fish species that might be harmed in pumps. Secondly, since this law requires the protection of certain fish species, that might be hindered by pumping stations.

Some national, provincial or regional policy translations of these legislations are mentioned as well. Other legislation and regulations, such as the Dutch Ecological Network (EHS) and Natura 2000 network are seen as reinforcements of other legislations. Respondents differed in opinion about least and most applicable legislations with regard to the ecological consequences of pumping stations. Furthermore, the obligations resulting from legislations were often found to be unclear.

5 respondents believe that their water board complies with the legislations they mentioned, 9 believe their water boards do not. None of these 9 respondents believe that this currently results in any consequences for their board. Several respondents stated that the Water Framework Directive and Eel Regulation at present only ask for a definition of objectives and programs of measures. The implementation of measures is not yet required by these legislations. On the other hand, some respondents believe that their board does not comply with the obligations resulting from the Benelux decision and the Flora and Fauna law.

Legislations are not generally thought to counteract each other. Some respondents mentioned that inconsistencies might exist within practical applications of these legislations. An example given is the fact that the enabling of fish migration which is demanded by the Benelux decision, might threaten the, by the Flora and Fauna law protected weatherfish, since this species has a very low competitive power.

6.2. Practices

In this section respondents are asked questions to assess their awareness and approval of actions concerning the mitigation of hazard and/or obstacles posed by pumping stations. Table 5 (appendix 3) summarizes respondents' answers on questions about water boards experiences with, obstacles encountered during and additional motives to take measures concerning hazards and obstacles posed by pumping stations. Moreover, respondents were asked to grade the influence of certain motives on the choice for a specific measure.

Respondents are generally aware of many types of measures that can be applied. However, little experiences exist with the execution of these measures. 6 respondents claimed that their board already performed studies on damage and mortality at pumping stations and 5 respondents stated that their board has experiences with fish friendly pumps or eel passages. Most respondents declared that weirs and larger pumping stations receive more attention in terms of performed research and measures taken. Costs and maintenance are mentioned most frequently as an obstacle for the implementation of measures. Some respondents also state that measures are often perceived to counteract quantitative water management. The enabling of fish migration and the protection of species is believed to be the primary motive for the implementation of measures. Besides this motive, efficiency and energy generation potential are believed to be very important motives in the choice between measures. However, respondents are generally convinced that all existing measures will utilize more energy than conventional pumping stations. Visibility and education are also thought to be important aspects for the choice between different measures.

Most water boards already formulated policy for fish stock management or fish migration. The content of these policies differs and none of these policies have officially come into force yet. Some policies do already include a budget and specific measures, whilst others only define that fish

migration needs to be taken into account at the renovation and construction of pumping stations. Most water boards surveyed and prioritized all the bottlenecks for fish migration within their managed area. These prioritizations are mostly based on characteristics such as the size of, the length of banks within, the structure of, or the function of the disclosed area. Sometimes the type of pump is accounted for as well.

6.3 Outcomes

In this section respondents are asked questions to assess their expectations of measures that can be used to solve the hazards and obstacles posed by pumping stations. Opinions about social acceptance, cost effectiveness and feasibility of different measures were asked. Furthermore, respondents were asked if any negative consequence might result from measures to solve the hazards and obstacles posed by pumping stations.

As mentioned above respondents are generally aware of many types of measures that can be applied. Nevertheless, ambiguity exist about the applicability of these measures and the cost effectiveness and feasibility of measures is not always approved. Most respondents stated that the social acceptability of measures is generally high, since the attention for animal wellbeing is growing. As mentioned before, measures are not always approved of amongst employees of water boards. Some respondents stated that especially an Archimedes screw pump is perceived as dated technology. Bypass facilities have the advantage of being visible and are therefore seen as a good measure for the creation of social support. In paragraph 6.2 it is explained that costs are seen as the largest obstacle for the implementation of measures. Respondents are generally convinced that technically opportunities are numerous, but that high cost and additional maintenance might result from complicated, additional structures. Fish friendly pumps are thought to result in lower costs than the additional structures necessary for the construction of bypass facilities. In contrast, the effectiveness of fish friendly pumps is disputed. Some respondents mentioned that these facilities are less effective than bypass facilities, since they do not enable continuous fish migration. It is thought not feasible to implement measures at each pumping station. All respondents agreed that a selection of the most important bottlenecks for fish migration needs to be made. Most boards already made such a selection with the above mentioned prioritization.

Although not seen as a serious obstruction for the implementation of measures, some negative (ecological) consequences which might result from the enabling of fish migration are recognized. Respondents mentioned that fish species with a low competitive power might be negatively affected, since these species benefit from isolation. Other negative consequences mentioned are the introduction of exotic species and the immigration of benthivore species.

Most respondents stated that they are satisfied with the current policy changes in their water board. Several respondents, however, did mention that more information is required on good practices in fish stock management and that the responsibilities and obligations resulting from legislations are currently not clear.

7. Conclusion, discussion and recommendations

7.1. Conclusion

Water managers are generally aware of the possible hazards and obstacles posed by pumping stations and of the possible measures to solve these. Nevertheless, respondents did not agree on the dimension and seriousness of these hazards and obstacles. Most respondents were also sceptical about the cost effectiveness and feasibility of measures which can be taken in order to construct fish friendly pumping stations. Especially when the large scale implementation of measures is considered.

This lack of approval results from two facts. Firstly, from the fact that insights in the ecological consequences of pumping stations are sometimes lacking (explained in chapter 6). Secondly, from the fact that information about costs, efficiency and effectiveness of measures is not widely available. Moreover, polder water bodies and the technical aspects of pumping stations can show a large variety within a single managed area. For these reasons ecological effects of pumping stations and costs, efficiency and effectiveness of measures will also vary amongst locations. One might argue that the implementation of measures is therefore also hampered by the fact that no “cooking book with ready to use measures” exists.

Since pumping stations fulfill an important role in drainage control for human safety, agriculture and infrastructure the acceptability of certain measures can be low amongst technicians and water managers. These tend to have more fate in widely utilized, proven techniques. Moreover, efficiency is seen as an important variable when pumping stations are designed and most respondents believe that efficiency will be lost when fish friendly pumping stations are created. Several respondents pointed out that they wish for simple measures, such as an adapted pump that can be utilized within the renovation cycle of pumping stations. These adjusted pump types are believed to be the most energy efficient measure available, since no additional pumps are required and no water is lost. Fish friendly pumps are also believed to be least costly, because their utilization within the renovation and construction cycle prevents additional costs. However, visible bypass facilities are seen as important measures which can increase ‘green reputation’ of a water board.

These hazards and obstacles are not perceived to result in large economical consequences for water boards. The declining eel stock, which might be partially related to pumping stations, does pose a economical threat for professional fisheries. However, fisheries themselves are probably the largest source of this decline (Vriese *et al.*, 2007). Motives of water managers to solve the hazards and obstacles posed by pumping stations therefore mostly lays within compliance with legislation.

Most respondents seem to be aware of legislations which are applicable to these problems fish might encounter. However, not all respondents were aware of every applicable legislation. Water managers also varied in opinion about the obligations which result from these legislations. This can be either due to a lack of awareness or due to a lack of approval of the relation between those legislations and the ecological consequences of pumping stations.

Although many laws and legislations are applicable to the protection of fish species and fish stock management, the responsibilities and enforcement resulting from these legislations are often not clear. The public wish for animal protection is growing (Werkman *et al.*, 2007) and this is reinforced by the general duty to care for all native flora and fauna (LNV, 2002). Although this growing attention is reflected in the definition of governmental policies, these do currently not result in stringent obligations.

Stringent obligations result from the Benelux decision and the targets set for the Ecological Network. Within the Benelux decision a clear objective is stated; fish migration needs to be enabled in all water bodies by 2010 (Benelux economical union, 1996; Nijboer, 2000). This is reinforced by the objectives stated for the areas representing the Dutch Ecological Network (EHS). One might argue, that represented water boards do not comply with obligations resulting from these legislations since no efforts have been made to enable fish migration at all pumping stations by 2010. However, it remains ambiguous who is responsible for the implementation of this decision, since it has never been incorporated into national policy. Officially, national, provincial as well as regional governments are responsible for the implementation of the Benelux legislation. As this legislation has never been translated into national policy, it remains generally unacknowledged and it appears that little consequences result from noncompliance.

The responsibilities and enforcement which results from the Water Framework Directive (WFD), Eel regulation and the European Habitat and Birds Directives are apparent, since these are translated into national policy. Nevertheless, these legislations cannot be directly connected to the hazards and obstacles posed by pumping stations, since assessments of the ecological effects of pumping stations are scarce. The WFD does not require member states to implement explicit measures, but obliges water managers to achieve their defined objectives. The measures that are necessary to achieve these objectives are determined by water managers themselves. Within the WFD objectives for ditches and canals a “good status” can easily be achieved in absence of migrating species. While these are species that are most likely affected by pumping stations. On the other hand, a so-called stand still principle is prescribed by the WFD. This implies that no further deterioration of water quality is allowed. Hence, one might argue that the implementation of fish friendly measures is at least required at the construction and renovation of pumping stations. Moreover, there are several arguments that can associate fish friendly measures to defined objectives for the WFD, Eel Regulation and Habitat and Bird Directives. These arguments can be used to ground decisions to implement these measures within programs of measures for these European Directives.

7.2. Discussion

Several comments can be made on general flaws of qualitative research. Some disadvantages of questionnaires are that respondents may forget important issues, answer superficially or misinterpreted questions (Descombe, 2007). To overcome these flaws, additional questions that provide insight in the knowledge present were sometimes asked.

Furthermore, biases can result from the unwillingness of respondents to answer questions and give grades (Descombe, 2007). The policies that are currently formed at water boards were often not yet approved by the general board and therefore may have contained information that respondents might not have wanted to reveal to the main public. It is also true that opinions of interviewed respondents might not be in line with the organization they stand for. In order to minimize these biases, answers remained anonymous and a clear distinction has been made between questions that asked for an opinion and questions that elaborated on the current status of policy and actions at a water board. The grades given should be interpreted carefully, since different points of reference might have been used. In order to assess points of reference, these questions were preceded by open questions.

The characteristics of water systems managed by the different represented water boards can vary. Since respondents only answered questions about the area managed by their own water board, differences within their answers can also result from the fact that these systems and the fish species that occur within these systems differ. Still, most polders that are discussed are low lying polders that are drained by pumping stations and commonly occurring migratory species in all these areas are eel and three spined stickleback.

It should also be mentioned that not all water boards that manage polder water systems are represented within this study. The water boards Hunze and Aa's, Noorderzijlvest, Zuiderzeeland and Zeeuws-Vlaanderen are boards that manage polder waters but are not represented in this study. Especially the first two of these water boards stand out compared to the represented water boards, since they have already implemented measures to solve the hazards and obstacles posed by pumping stations (Riemersma & Kroes, 2004; Kruitwagen *et al.*, 2006; Schreuder *et al.*, 2008).

7.3. Recommendations

7.3.1. Recommendations for further research

Both the inventory and the interview results of this study indicate that assessments of the ecological consequences of pumping stations are scarce. More knowledge about these ecological consequences is required for a better grounding of the decision whether or not to implement measures to create fish friendly pumping stations.

The seriousness of these consequences can be assessed by studying fish damage and mortality induced by the most frequently occurring type of pumping stations. The influence of pump type, rotation speed, head and type of waste collection structure should also be measured, in order to determine the required adaptations to minimize the damage induced. A better understanding of fish recruitment at both the up- and downstream sites of pumping stations provides insight into the seriousness of the obstacles posed.

The dimensions of these consequences can be assessed by studying the effects of pumping stations on polder fish assemblages. Moreover, the possible cascade effects that could result from the facilitation of fish migration deserve more attention. A combination of studies on migratory behavior of polder fish species, monitoring and evaluation of community structure before and after hazards and obstacles are removed or mitigated and modeling studies could provide this information.

An examination of fish behavior around and within bypass facilities and fish friendly pumps can increase our understanding of the effectiveness of these measures. An assessment of the influence of a counter natural flow direction, sound and vibration on the migratory behavior of certain fish species determines the willingness of fish to pass through these constructions.

In order to honestly compare different measures criteria such as maintenance requirements, energy utilization, capital costs, applicability at high heads and amount and type of required construction materials and the lifetime of a construction also have to be determined. A comparison of different pump types and other measures, based on these criteria could provide an overview of the sustainability of (fish friendly) pumping stations. An examination of the cost effectiveness of 'fish friendly' measures in comparison to other measures that aim to improve fish stocks could aid water managers in the definition of programs of measures that aim to improve fish stocks.

7.3.2. Policy recommendations

This study found that responsibilities, obligations and jurisdiction of legislations that concern the hazards and obstacles posed by pumping stations are often not clear.

It might be a task for the Dutch national government to provide more clarity on these issues, for example by translating the European Eel Regulation and the Benelux decision into a single national policy guideline. Well defined and surveyed national policy can provide a joint guideline for all water boards. Moreover, more stringent policy is important for the grounding of the decision to implement measures to mitigate the hazards and obstacles posed by pumping stations.

Migratory species are currently not well represented in Water Framework Directive (WFD) default criteria for polders, while both three spined stickleback and eel are classified as typical polder species. Since the Eel Regulation and the Benelux decision do require attention for these species, these WFD criteria could be adapted as such that the presence of these species influences the assessment of water quality required by this directive.

Assessments of the effectiveness of measures to solve the hazards and obstacles posed by pumping stations are still scarce and public awareness of these hazards and obstacles is still low. Hence, the goal of the implementation of these measures should not only lay within the rehabilitation of fish communities, but also in their contribution to the assessment of ecological effects of pumping stations. Every measure that aims to alter an ecosystem will encompass uncertainties. A learning-by-experience process can provide valuable information and thereby reduce these uncertainties. Moreover, the implementation of measures enables 'fish friendly' techniques to prove themselves.

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9. Appendices

Appendix 1; Questionnaire

Organisatie en functie

- 1) Wat is uw functieomschrijving binnen het water/ hoogheemraadschap?
- 2) Bent u op de hoogte van de onderbouwing bij het beleid en beslissingen ten aanzien van visschade en vismigratie bij poldergemalen?
- 3) In hoeverre bent u in staat om beleid en de uitvoering daarvan op dit gebied te beïnvloeden?

Aanleiding

- 4) Ondervinden vissen naar uw mening problemen bij gemalen?
Kunt u hier een cijfer aan geven, waarbij 0 = geen problemen en 5 = ernstige problemen?
 - a) Zo nee, beoordeeld u dit op basis van monitoring, literatuur of expert judgement?
 - I. Ondervinden vissen naar u mening wel problemen bij andere kunstwerken, welke?
 - II. Bent u op de hoogte van de studies naar visschade bij gemalen en wat vindt u hiervan?
 - b) Zo ja, welke en beoordeeld u dit op basis van monitoring, literatuur of expert judgement?
 - I. Kan er onderscheid gemaakt worden in specifieke soorten die problemen ondervinden en welke zijn dit (doelsoorten)?
 - II. Kan er onderscheid worden gemaakt in problemen op stroomopwaartse- of afwaartse route?
 - III. Verwacht u deze problemen op het schaalniveau van individuen of populaties?
- 5) Denkt u dat visschade en migratieknelpunten bij gemalen economische gevolgen kunnen hebben ..
Kunt u hier een cijfer aan geven, waarbij 5= baten en -5 = kosten?
 - a) Voor beroeps en/ of sportvisserij, waarom?
 - b) Voor recreatie en/ of omwonende (boeren), waarom?
 - c) Voor waterschap en/ of andere overheidsinstellingen, waarom?
 - d) Voor andere actoren, waarom?
- 6) Denkt u dat visschade en migratieknelpunten bij gemalen sociale gevolgen kunnen hebben ..
Kunt u hier een cijfer aan geven, waarbij 5 = acceptatie en -5 = weerstand?
 - a) Voor beroeps en/ of sportvisserij, waarom?
 - b) Voor recreatie en/ of omwonende (boeren), waarom?
 - c) Voor waterschap en/ of andere overheidsinstellingen, waarom?
 - d) Voor andere actoren, waarom?
- 7) Welke wet en regelgeving is naar uw mening van toepassing op visschade en vismigratie bij gemalen?
- 8) Denkt u dat er in uw beheersgebied aan deze wettelijke kaders wordt voldaan?
 - a) Zo nee, verwacht u dat hier consequenties aan verbonden zijn? Welke?

- b) Zo ja, denkt u dat met deze wetgeving de verschillende bovengenoemde belangen zijn behartigd?
- 9) Ondervindt u tegenstrijdigheden in verschillende genoemde wetgeving?
- a) Zo ja, welke en kunnen die worden verkleind of weggenomen?

Uitvoering

- 10) Welke ervaring(en) heeft uw schap op het gebied van visschade- en passeerbaarheid bij poldergemalen?
- 11) Van welke maatregelen voor het beperken van visschade en/ of het passeerbaar maken van gemalen bent u op de hoogte?
- ⇒ Heeft u een van de volgende maatregelen niet genoemd omdat u hier niet van op de hoogte bent of om een andere reden? Welke?
- Natuurlijke maatregelen, zoals inundatie of tijdelijk inundatie van polders
 - Technische maatregelen, zoals bypasses, bypasses met pompen (vissluis, manshanden gemaalpassage), mechanische- en gedragsbarrières, visvriendelijke pompen
 - Aangepast beheer, zoals via sluizen of inlaten of aanpassen omwentelingssnelheid van gemaal
- 12) Bestaan er belemmeringen voor het uitvoeren van deze maatregelen?
- a) Zo nee, waarom denk u dat deze maatregelen niet op grote schaal toegepast worden?
- b) Zo ja, welke?
- 13) Bestaan er, naast het beperken van visschade en het mogelijk maken van vismigratie, andere motieven voor het nemen van deze maatregelen?
- a) Zo nee, denk u dat ecologische motieven voldoende aanleiding geven voor het uitvoeren van deze maatregelen?
- b) Zo ja, welke en welke invloed hebben deze op besluiten t.a.v. het uitvoeren van deze maatregelen?
- ⇒ Zou u de volgende (en eigen genoemde) motieven een cijfer kunnen geven, waarbij 0 = geen invloed en 5 = veel invloed
- Verhogen hydraulisch rendement
 - Opwekken van energie
 - Zichtbaarheid (voor het creëren van draagvlak)
 - Educatieve waarde
- 14) Is het beperken van visschade en het bevorderen van connectiviteit bij gemalen verankerd in het beleid van uw schap?
- a) Zo nee, waarom niet?
- b) Zo ja, hoe en hoe ver is de implementatie hiervan?

Consequenties (verwachtingen)

- 15) Hoe schat u de kosteneffectiviteit, haalbaarheid en aanvaardbaarheid van bovengenoemde maatregelen voor het beperken van visschade en het bevorderen van connectiviteit bij gemalen in?
- a) Aan welke van de besproken maatregelen geeft u de voorkeur en waarom?

- 16) Denkt u dat er negatieve consequenties verbonden kunnen zijn aan het vispasseerbaar maken van gemalen?
- 17) Denkt u dat het beleid ten aanzien van visschade en vispasseerbaarheid bij gemalen en de uitvoering daarvan in de toekomst zal en/ of moet veranderen?
- a) Zo nee, waarom niet?
 - b) Zo ja, hoe en binnen welk overheidsniveau?

Afsluiting

- 18) Wat is op dit moment uw meest prangende vraag ten aanzien van de besproken thema's?
- 19) Heeft u zelf nog opmerkingen of ideeën die u graag kwijt wilt, welke met een van deze thema's te maken heeft of op een andere manier volgens u relevant is?

Appendix 2; Polder fish requirements & damage

Table 2, Habitat requirements and preferences of Dutch polder fish

| species | | | habitat requirements and preferences | | | | | | |
|---|--------------------------|--|--------------------------------------|-----------------|--------------------|---|--------------------------|--|-------------------------------|
| NL | Eng | Latin | Migration | Flow preference | Reproductive guild | habitat degradation | Substrate preference | Swim bladder | Max length |
| | | | (FishBase, retrieved in 2008) | (RIZA, 2002) | (Balon, 1984) | (Kroes et al., 2000; FishBase, retrieved in 2008) | (Kroes et al., 2000) | (Lucas & Barras, 2001; Larinier, 2001) | (FishBase, retrieved in 2008) |
| KRW | | | | | | | | | |
| Brasem | Bream | <i>Abramis brama</i> | potamodromous | Eurytope | Polyphile | tolerant | detritus, mud, sand | Physostomous | 82 cm |
| Karper | Carp | <i>Cyprinus carpio</i> <i>Scardinius erythrophthalmus</i> | potamodromous | Eurytope | Phytophile | tolerant | detritus, mud, sand | Physostomous | 120 cm |
| Ruisvoorn | Rudd | <i>Scardinius erythrophthalmus</i> | potamodromous | Limnophile | Phytophile | sensitive | detritus, mud, sand | Physostomous | 51 cm |
| Tiendoorlige stekelbaars | Nine-spined stickleback | <i>Pungitius pungitius</i> | anadromous | Limnophile | Ariadnophile | tolerant | detritus, mud, sand | Physoclastic | 9 cm |
| Vetje | Sunbleak | <i>Leucaspis delineatus</i> | potamodromous | Limnophile | Phytophile | tolerant | detritus, mud, sand | Physostomous | 10 cm |
| Giebel | Gibel carp | <i>Carassius auratus gibelio</i> | potamodromous | Eurytope | Phytophile | tolerant | - | Physostomous | 45 cm |
| Snoek | Pike | <i>Esox lucius</i> | potamodromous | Eurytope | Phytophile | - | detritus, mud, submerged | Physostomous | 150 cm |
| Kleine modderkruiper | Spined loach | <i>Cobitis taenia</i> | potamodromous | Eurytope | Phytophile | - | detritus, mud, submerged | Physoclastic | 12 cm |
| Kroeskarper | Crucian carp | <i>Carassius carssius</i> | potamodromous | Limnophile | Phytophile | tolerant | - | Physostomous | 64 cm |
| Zeelt | Tench | <i>Tinca tinca</i> | potamodromous | Limnophile | Phytophile | - | detritus, mud, submerged | Physostomous | 70 cm |
| 3-doornige stekelbaars | Three-spined stickleback | <i>Gasterosteus aculeatus</i> | anadromous | Eurytope | Ariadnophile | tolerant | none | Physoclastic | 11 cm |
| & Habitat directive & Eel regulation | | | | | | | | | |
| Grote modderkruiper | Weatherfish | <i>Misgurnus fossilis</i> | potamodromous | Limnophile | Phytophile | - | detritus, mud, submerged | Physoclastic | 30 cm |
| Bittervoorn | Bitterling | <i>Rhodeus sericeus</i> | potamodromous | Limnophile | Ostracophile | sensitive | detritus, mud, submerged | Physostomous | 10 cm |
| Paling (Aal) | Eel | <i>Anguilla anguilla</i> | catadromous | Eurytope | Pelagophile | tolerant | detritus, mud, submerged | Physoclastic | 155 cm |
| Non indicator/ target species | | | | | | | | | |
| Baars | Perch | <i>Perca fluviatilis</i> | anadromous | Eurytope | Phytolithophile | tolerant | none | Physoclastic | 60 cm |
| Blankvoorn | Roach | <i>Rutilus rutilus</i> | potamodromous | Eurytope | Phytophile | tolerant | none | Physostomous | 45 cm |
| Kolblei | White bream | <i>Abramis bjoerkna</i> | potamodromous | Eurytope | Polyphile | tolerant | detritus, mud, sand | Physostomous | 36 cm |

Migratory guilds

| | |
|---------------|-----------------------------------|
| anadromous | adults migrate upriver to spawn |
| catadromous | adults migrate to sea to spawn |
| potamodromous | adults migrate within fresh water |

Flow preference

| | |
|------------|---|
| rheophile | some or all stages of life history are confined to lotic waters |
| limnophile | all stages of life history are confined to lentic waters with macrophytes |
| eurytope | all stages of life history can occur in both lotic and lentic waters; 'habitat generalists' |

Reproductive guilds

| | |
|-----------------|--|
| Lithophile | eggs deposited on boulder, cobble, gravel and sand substrates |
| Phytophile | eggs deposited on aquatic or terrestrial vegetation |
| Pelagophile | eggs deposited in the water column |
| Polyphile | eggs deposited both on substrate and macrophytes |
| Phytolithophile | eggs deposited on submerged vegetation, logs/branches or in natural cavities |
| Ariadnophile | males create saliva nests |
| Ostracophile | eggs deposited in the cavity of freshwater mussels |

Swim bladder type

| | |
|--------------|--|
| Physostomous | connection tube between the swim bladder digestive canal |
| Physoclastic | bladder is not connected with the digestive tract |

Table 3, Fish damage & mortality at Dutch and Belgium pumping stations

| Type of pump | Species caught | Capacity (m3/min) | Rotation speed (rpm) | Damage percentage scalefish | eel | Mortality percentage scalefish | eel | Reference |
|--------------------|---|-------------------|----------------------|-----------------------------|------|--------------------------------|-----|--|
| Archimedian screw | Eel, Roach | 35 | 37 | 25,4 | 36,5 | 19,6 | | Denayer & Belpaire, 1992 |
| Archimedian screw | Eel, Roach, Perch, Bream, Carp | 30 | 39 | 10-20 | 10 | 10-44 | | Germonpré <i>et al.</i> , 1994 |
| Archimedian screw | Roach and Bream dominate Eel, Roach, Pike, Rudd, Carp, White Bream, Ruffe, Gudgeon, Sunbleak, Tench, Ide | 100 - | | 13 | - | 1 | | Lange & Mekx, - 2005 |
| Archimedian screw | | - | | 0 | 0 | 0 | | Merx & Vriese, 0 2006 |
| Centrifugal pump | Eel, Roach, Perch, Bream | 60 | - | 33-68 | 1 | 12-16 | | 0 Germonpré <i>et al.</i> Kruitwagen & |
| Centrifugal pump | Eel and Bream dominate | 1080 | 59 | 1 | 0 | <1 | | 0 Klinge, 2007 |
| Centrifugal pump | Eel and White Bream dominate | - | | 100 | 30 | 100 | | Wintermans, 8 2005 |
| Screw pump (axial) | Eel, Roach, Crucian Carp | 60 | 500 | 100* | 100* | 100* | | 100* Germonpré <i>et al.</i> |
| Screw pump (axial) | Eel, Roach, Perch, Bream, Pike, Rudd, Ruffe, Common Bleak, River Lamprey, Gudgeon | 37,5 | 735 | 100 | 100 | 100* | | Kruitwagen <i>et al.</i> , 2006 |
| Screw pump (axial) | Perch and Ruffe dominate | 20 | | 13 | - | 1 | | - Lange & Mekx, |
| Screw pump (axial) | Roach and Bream dominate | 2500 | 80 | 19 | 30 | 4 | | 0 Kroes <i>et al.</i> , |
| Screw pump (axial) | Eel, River Lamprey | 15600 - | | 0 | 71 | 0 | | 52 Kruitwagen & Klinge, 2008 |

* fish over 10 cm

Appendix 3; Interview results

Table 4, Delegates estimation of the ecological, economic and social consequences of pumping stations

| Delegates | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | |
|------------------------------|---------------------------------------|--------|-------|---|-----|-------|-----|---------------|-------|---------|------------|---------|----|-------|-------|--------|
| Ecology | 4/5 | 1 | 5 | 3/4 | - | 4 | 5 | 3 | 1 | 5 | 5 | 2/3 | - | 3 | 5 | |
| Economy | Fisheries | 0 | 0 | 2 (P) | 3 | 2 (P) | 3/4 | 2 (P) | 1 (P) | 4 (P) | 2 (P) | 3 (P) | 0 | costs | 4 | 2/3 |
| | Recreation and human settlements | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0/1 | 1 | 0 | 0 | 0 | 1 |
| | Water board (other GO) | 0 | 0 | 3 | 4/5 | 1 | 0 | 0 | 1 | 1 | 2 | 4 | 1 | costs | 5 | 2/3 |
| | Others | - | - | - | - | - | - | - | - | - | - | 3, NO | - | - | - | - |
| Social acceptance | Fisheries | 4 | 1 (R) | 2 | 4 | 4 (R) | 3/4 | 2 (P)/3 (R) | 2 | 4/5 (P) | 5 (P) 4(R) | 5 (P) | 1 | 2 (R) | 5 | 0/1 |
| | Recreation and human settlements | 2 | 0 | 0 | 3 | 3 | 2 | (-4, farmers) | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0/1 |
| | Water board (other GO) | 5 | 0 | 0 | 4 | 1/2 | 4 | -1 | 3 | 0 | 4 | 4 | 2 | 2 | 4 | 0/1 |
| | Others | AP, NO | - | 3, NO | - | 5, AP | - | 4, AP | - | AA | - | 3, NO | AP | AA | - | APO |
| Obligations | Legislation | FF | WFD | RP | FF | FF | FF | FF, WFD | FF | WFD, ER | FF | PP/ RP | ER | FF | N2000 | FF, PP |
| | Compliance | no | yes | yes | no | yes | no | no | no | no | no | no | no | no | no | no |
| | Consequences | no | - | - | no | - | no | - | - | no | no | not yet | no | - | - | - |
| Ecological consequences | 0 = none and 5 = serious consequences | | | BeNeLux Decision | | | | | | | | | | | | |
| Economic consequences | -5= benefits and 5 = costs | | | Water Framework Directive | | | | | | | | | | | | |
| Social acceptance | -5= acceptance and 5= resistance | | | Eel Regulation or National Eel Management Plan | | | | | | | | | | | | |
| | | | | Flora and Fauna Legislation | | | | | | | | | | | | |
| Animal Party | AP | | | 4th Water Resources Act (nota waterhuishouding) | | | | | | | | | | | | |
| Nature Organizations | NO | | | Policy Decision freshwater fisheries | | | | | | | | | | | | |
| Animal Protection Organizati | APO | | | Provincial and Regional Policy | | | | | | | | | | | | |
| Animal Activists | AA | | | December Bill | | | | | | | | | | | | |
| | | | | Natura 2000 | | | | | | | | | | | | |

Table 5, Experiences, obstacles and motives for the implementation of measures which solve the hazards and obstacles posed by pumping stations and current regional legislation

| Delegate | Experience | Obstacles | Motives | | | | Regional legislation | |
|----------|--|--|--|-------------------|------------|-----------|----------------------|---|
| | | | Hydraulic efficiency increase | Energy generation | Visibility | Education | | |
| 1 | Fish passes at weirs, Study: Fish mortality at PS, Adjusted De Wit Archimedes screw at 4 PS | Lack of space, Introduction exotic species, Cost-effectivity, Lack of knowledge on effectivity, Large variation in bottlenecks and possible measures | Emigration benthivore fish, Utilization by other organisms | 3 | 5 | 5 | 4 | Indirectly through the WFD Coming soon: Policy Bill Fish Stock Management |
| 2 | Fish passes at weirs | Lack of knowledge on scale of problem | - | 3 | - | 3 | 3 | Management Bill Fish |
| 3 | Eel passes, Pumps jammed by eels | Costs | - | 4 | 4 | 1 | 1 | Policy Bill Fish Stock Management (waiting for approval) |
| 4 | Study: Fish mortality at reservoir PS and 1 polder PS, Adapted Archimedean screw | Knowledge on effectiveness measures, Costs | PR (visibility) | 4 | 4 | 3 | 3 | Vision for Fish Stock Management (not approved) |
| 5 | Study: Fish mortality at reservoir PS, Plans for fish pass | Counteracting quantitative water management, Costs | Visibility | 2 | 1 | 1 | 1 | Vision on Fish migration (approved by daily board, not by general board) |
| 6 | Fish pass at PS, Adjusted management at sluice | Human safety hampers possibilities, Costs, Lack of knowledge on scale of problem | - | 4 | 4 | 1 | 1 | Coming soon: Fish Migration Plan |
| 7 | Pumps jammed by eels | Costs, Maintenance | Potential energy gain | 4 | 4 | 2 | 2 | Fish migration plan |
| 8 | Pumps jammed by eels, Pump chosen for its fish-friendliness, Consequences for fish are accounted for at pump renovation | Costs, Maintenance | Visibility | 4/5 | 2 | 2 | 2 | Policy Bill Fish |
| 9 | Possible solutions defined for 2 weirs, Fish recruitment measured at PS | Costs, Effectiveness within freshwater (lure stream) | - | 5 | 1 | 0 | 0 | None, topic on agenda through the Water Management Plan |
| 10 | 3 eel passes, Plans for monitoring of passes & PS | Costs, Maintenance, Preference to utilize proven techniques | Other organisms might benefit | 3 | 3 | 3 | 3 | Fish migration Proposal (not approved by board) |
| 11 | Study: Fish mortality at PS, Measures designed for prioritized bottlenecks | Costs | Chain effect (water quality and birds), Perception | 3/4 | 1 | 5 | 5 | Framework Bill Fish (approved by daily board, not by general board), within the Water Management Plan and WFD Programme of Measures |
| 12 | Fish passes at weirs | Cost, Need & necessity ambiguous | Artefacts can disturb landscape, Increase problem approval | 5 | 5 | 4 | 3 | Indirectly through the WFD programme of measures and Water Management Plan |
| 13 | Study: Fish mortality at PS | Costs, Lack of awareness, Feasibility of solutions | - | - | - | - | - | Fish migration policy plan (not approved by our board), on agenda through Water Management Plan |
| 14 | Fish passes at weirs, Adjusted management of inlet sluices, De Wit pass at PS | Costs | Other organisms might benefit | 5 | - | 1/2 | 1/2 | None, topic on agenda through the Water Management Plan |
| 15 | Fish locks at marine-freshwater transitions, Fish friendly PS and siphon passage (initiated by National forest management institute) | Large scale fish emigration, Little solutions available, Maintenance | - | 0 | 0 | 4 | 4 | Policy Bill Fish |

PS: pumping stations