Fish swim back and forth again

Final report of the practical test of innovative facilities in pumping stations

Report 2011-096

J.H. Wanink
R. Bijkerk
G.H. Bonhof
N. Bouton
H. Slabbekoorn

Universiteit Leiden

Koeman and Bijkerk
Ecological research and consultancy

Visiting address	Oosterweg 127 Haren
Postal address	P.O. Box 111 9750 AC Haren
Telephone	050 8200018
Telefax	050 8200013
E-mail	info@koemanenbijkerk.nl
Website	www.koemanenbijkerk.nl

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Cover photo: Positioning of a stock fyke net near the overfall fishway near the Abraham Kroes pumping station (photo: Koeman and Bijkerk)

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Figure 9 *Trapping structure behind the outflow orifice of the Kralingse Plas pumping station (photo: Koeman and Bijkerk).*

3.4 Kralingse Plas Pumping Station

3.4.1 Starting Situation and Adaptations

Located between the basin lock and the marina, in the southwest corner of the Kralingse Plas in Rotterdam (see Annex I). The pumping station pumps excess water from the Kralingse Plas (circa 100 ha) into the Rotte (Figure 9). The pumping station was equipped with a Flygt submersible pump with a capacity of 25 m^3/min. The water head is of circa 1.60 m.
In the autumn problems occurred in respect of fish migration when the outward migrating fish could only reach the Rotte via the pumping station. Within the scope of the *Integral plan Kralingse Plas* a wide range of measures has been implemented to turn the lake into a biologically healthy and clear water system. Thanks to Active Biological Management the fish population has been adapted to the changed circumstances. In order to optimize the outward migration of the fish in this system, it was decided to replace the pumping station pump with a fish safe axial flow pump, the so-called fish safe axial fish friendly pump (Nijhuis / FishFlow Innovations) with a capacity of 30 m^3/min. Because of the differences between the fish community in the Kralingse Plas and that in the Rotte, no fish bypass was installed. Therefore only outward migration is possible to the Rotte.

3.4.2 Global Results

Acoustic Research

The Kralingse Plas pumping station pump is the only genuine low noise pump.
This will have a positive effect on a possible passage through the lock, and also on the number of fish that will pass through the pumping station. The results indicate success: much greater numbers and stocks transit via the pumping station. The damage percentage is extremely low.

Fish Monitoring

Before and after the adaptation the stocks were dominated by huge amounts of small perch, an indication that after the Active Biological Management the lake is still in a pioneer stage. Ruffe, a second eurytope, was mainly found in very large numbers after the adaptation. After the adaptation the number of species in the stocks increased from three to eight and the target species eel was extremely well represented. With the exception of the limnophilic rudd all other species are eurytope. Rudd was the only species in the stocks not to use the pumping station. However, during passage monitoring the rheophilic orfe was caught, which had been missing from the stocks.

Before the adaptation a relatively small number of fish from the ‘other species' category present before the pumping station used the pumping station pump as a migration route. This concerned three eurytope species dominated by the juvenile perch. Of the target species silver eel was present, a relatively large number of which passed through the pumping station. After the adaptation a relatively large number of the 'other species' stocks passed through the pumping station. The six eurytope species all passed, but the only limnophile, i.e. rudd, did not. Rheophilic orfe was only caught behind the pumping station. Of the large stocks of eel (yellow eel and silver eel) only a relatively small number used the new pumping station pump as a migration route.

The damage percentage to passers differs considerably between the old and new situation. In 2009 nineteen silver eels (length: 60-78 cm) passed and were all killed by the pumping station pump. Of the 'other species' perch, ruffe and pike-perch passed, but only the perch incurred damage. Although these were small perch (10-12 cm) the damage percentage was of 32.0% (n=1323). The damage percentage for all passing fish (10-12 cm) amounted to 29.4% (n=1503). In 2011 three silver eels (72-76 cm) passed through the new pump unscathed. At the time the length range of passing perch was greater (7-24 cm), but the damage percentage was greatly reduced to 0.04% (n=17376). Of the whitefish that did not pass in 2009 mainly bream (378 per night fyke) and roach (183 per night fyke) passed through the pumping station in relatively large numbers in 2011. Of the passing bream (6-23 cm) 0.32% (n=1892) was damaged. For roach (8-24 cm) no damage was found (n=915). The damage percentage for all passing fish (6-76 cm) amounted to 0.06% (n=27048).

Conclusion

The new fish safe axial fish friendly pump is very quiet. The number of passing silver eels dropped slightly after the adaptation, but scaly fish passed in far greater numbers, both in absolute numbers and in proportion to the stocks. The damage percentage dropped from 29.4% to 0.06%. Fish safety and passability improved considerably.

4 Results per Research Theme and Question

This chapter discusses the research questions on the basis of the following themes: *fish safety*, *fish passability*, *sound emission*, *pump output* and *the contribution of adaptations to the WFD (Water Framework Directive) objectives*. Not yet reported monitoring after the adaptations in the autumn of 2011 and in the spring of 2012, is elaborated in detail by means of graphs. Results of the baseline measurements have been included in the tables insofar as they are relevant for the comparison.

4.1 Fish safety

This paragraph states the percentage of the fish that was damaged while passing through the central pumping station pump.

4.1.1 Question 1 – Does any damage occur during the fish passage through the various adapted pumping station pumps (fish safe axial fish friendly pump, fish safe pipe conveyor, fish friendly screw conveyor) and the applied facilities?

2011 Autumn Results per Pumping Station

Kralingse Plas Pumping Station (fish safe axial fish friendly pump)

Figure 20 shows the scaly fish length-frequency distributions for the total catches of the stocks fyke nets and the fyke nets behind the pumping station. This Figure also shows the percentage of damaged fish (visible damage or dead) per length class. The peaks of the scaly fish having passed through the pumping station and that of the stocks virtually overlap. This is mainly due to the dominance of small perch.
The percentage of damaged fish is very low. The average damage percentage for all passers is 0.06% (Table 8). The damage percentage was somewhat higher (<2%) for the smallest fish only, approximately 6 cm long. The percentage of damaged fish does not increase with the increased length of the fish.
The 95% confidence interval of the average of all passing fish is sufficiently small to be able to make a statement regarding the damage percentage. This also applies for the damage percentages of the ≤15 cm length classes of the freshwater perch (0.04%) and carp (0.18%) families and for large (>15 cm) freshwater perch and carp families (both families: 0%) (see Table 1). The unscathed passage of three silver eels, with lengths of 72, 73 en 76 cm (Figure 21) was quite remarkable.
This small number of passing eels resulted in a large 95% confidence interval, so that as opposed to the baseline monitoring in 2009, in which 19 silver eels passed, which were all killed, no reliable damage percentage could be ascertained.

For the Kralingse Plas pumping station clear differences were noted in the percentage of damage to fish, between the old and new situation. In 2009 all nineteen passing silver eels (length: 60-78 cm) were killed by the pumping station pump. In 2011 three silver eels (72-76 cm) passed the new pump unscathed.

Tabel 8 *Catch results per pieces in the trapping structure behind the Kralingse Plas pumping station in the autumn of 2011 and during the baseline measurement in 2009.*

Spieces	Number of passers		Passers night fyke		Number damaged		Percentage damaged		Length (cm) unscathed		Length (cm) damaged	
target spieces	2009	2011	2009	2011	2009	2011	2009	2011	2009	2011	2009	2011
Eel (silver)	19	3	3,8	0,6	19	0	100	0		72-76	60-78	
Other spieces												
Perch	1323	17376	264,6	3475,2	423	7	32	0,04	10-12	7-24	10-12	6-10
Roach		915		183		0		0		8-24		
Bream		1892		378,4		6		0,32		6-23		6-9
Silver bream		1		0,2		0		0		16		
Ruffe	121	6843	24,2	1368,6	0	2	0	0,03	10	6-10		8-9
Pike-perch	40	15	8	3	0	0	0	0	11	12-17		
Orfe		3		0,6		0		0		14-16		
Total	1503	27048	300,6	5409,6	442	15	29,4	0,06	10-12	6-76	10-78	6-10
number of target spiec	1	1										
Number of other spiece	3	7										

The new pumping station pump also made fewer victims among the scaly fish.
Before the adaptation perch, ruffe and pike-perch passed and only the perch incurred damage. Although the fish were small (10-12 cm), the damage percentage was of 32.0% (n=1323). In 2011 the length range was greater (7-24 cm), but the damage percentage was considerably reduced 0.04% (n=17376). Of the other six species that passed the pumping station in 2011, not a single damage case was noted for roach (n=915), Silver bream (n=1), pike-perch (N=15) and orfe (n=3).
Here it should be noted that for Silver bream and orfe the number of passers was too low to make a statement. Bream and ruffe incurred damage percentages of respectively 0.32% (n=1892) and 0.03% (n=6843).

For the Kralingse Plas pumping station there is no trend in the damage percentage per fish length either. In 2009 all passers had a length of 10-12 cm, in which perch displayed the highest damage percentage (32%). However, only when silver eel is included in the calculation do we notice a positive trend as the large silver eels displayed 100% damage. It is striking that in 2011 all damage cases concerned the smallest length class (1-10 cm). The damage percentage amounted to 0.06% (n=26685). There was absolutely no damage for length classes 11-15 cm (n=257), 16-20 (n=93) and 21-25 cm (n=10).

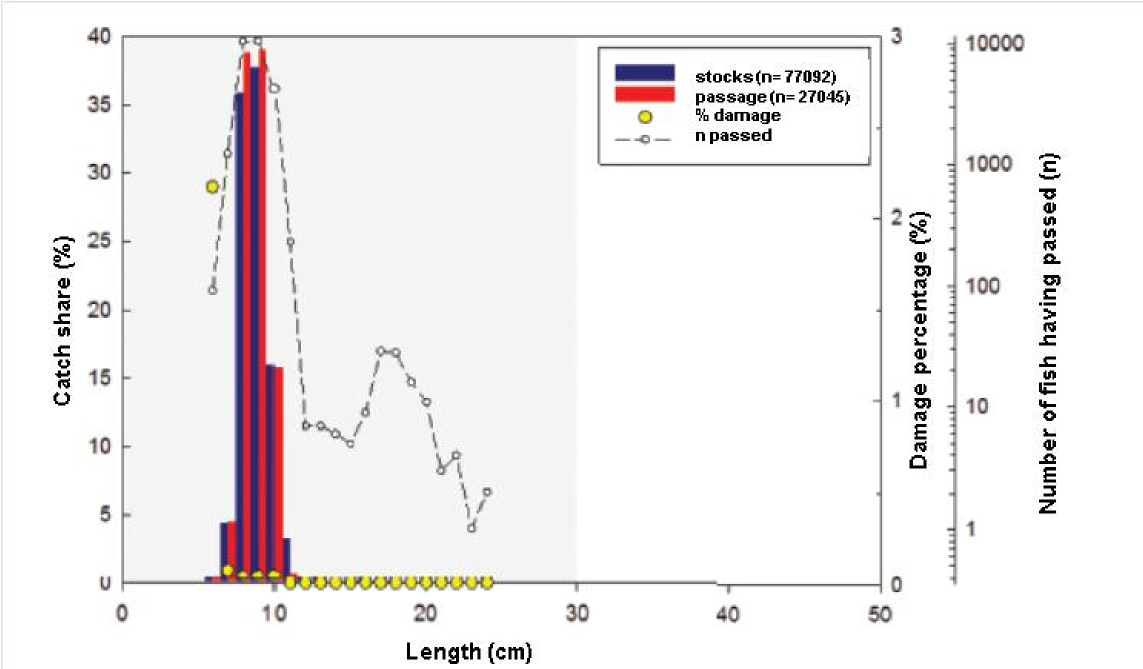

Figure 20
Length-frequency distribution of the total catches of scaly fish, passed numbers and damage percentages in the stocks fyke nets and the trapping structure behind the Kralingse Plas pumping station in the autumn of 2011. Up to a length of 30 cm the calculation occurs with 1-cm length classes, above that with 10-cm length classes.

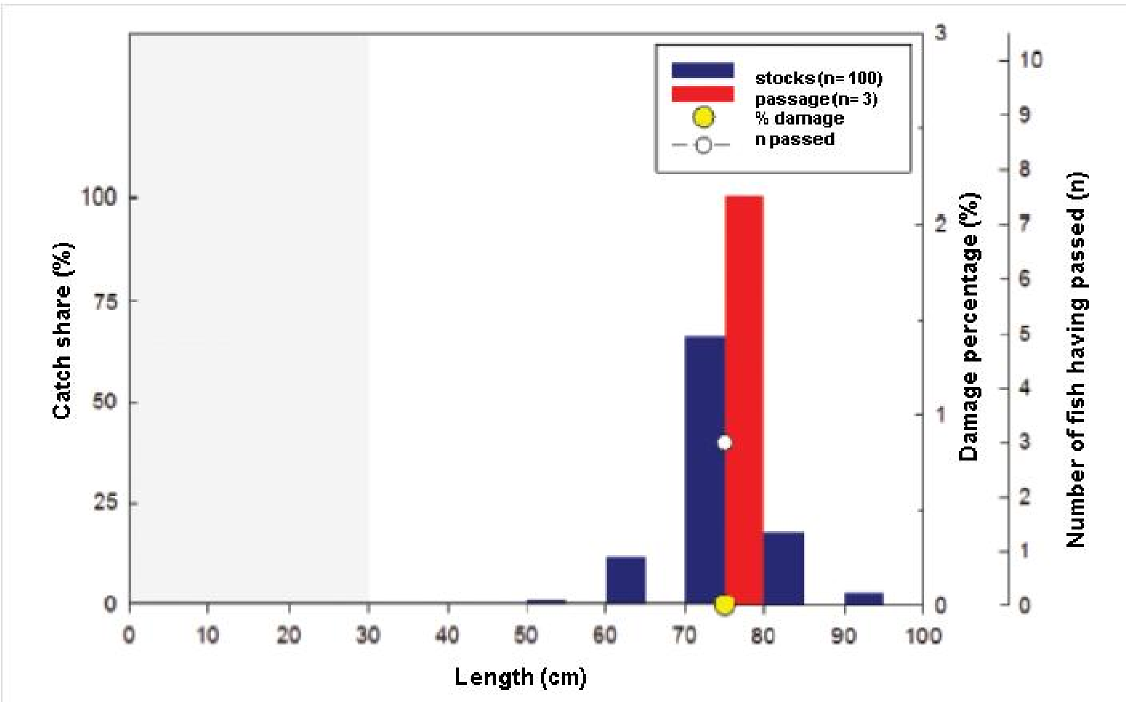

Figure 21
Length-frequency distribution of the total catches of eel, passed numbers and damage percentages in the stocks fyke nets and the trapping structure behind the Kralingse Plas pumping station in the autumn of 2011. Up to a length of 30 cm the calculation occurs with 1-cm length classes, above that with 10-cm length classes.

4.2 Fish Passability

This paragraph investigates to what extent the fish present near the civil engineering works actually use the pumping station pump or the realised facilities.

4.2.1 Question 3 – Which part of the fish stock that proceeds to the pumping stations (and the lock) actually uses the route via the pumping station pump to pass the pumping stations (comparison of traditional pumps with fish safe axial fish friendly pump, fish safe pipe conveyor and fish friendly screw conveyor)?

2009 and 2011 Autumn Results per Pumping Station

Kralingse Plas Pumping station (fish safe axial fish friendly pump)

The stocks determinations in 2011 occurred between 3 October (fyke nets set) and 16 December, in which period the fyke nets were emptied nineteen times (Annex II). The reported catch amounts represent the average value during the period as from the previous raising of the fyke nets. The catches of 14 October and 1 November are an exception to this. Indeed, these values are only based on four night fykes due to the theft of fyke nets in the intermediate period. There is no question of a trend in the stocks during the research period, even though the numbers of scaly fish appear to be slightly higher in the second half of the stocks determinations. The five passage determinations all appear to lie within a high stock of scaly fish, even though this has not been demonstrated for 28 October, due to the unavailable fyke nets. Two passage determinations coincide with the peaks in silver eels at the beginning of November (also a high stock of yellow eel) and in early December. For the baseline measurements performed in 2009 (Kruitwagen & Klinge 2010a) the stocks of scaly fish and the distribution of the passage determinations is comparable to that of 2011. In 2009 no eel was found in the stocks fyke nets.

Table 17 *Catch results per species in the stocks fyke nets before the Kralingse Plas pumping station in the autumn of 2011 and during the baseline measurement in 2009.*

Spieces	Stocks (n)		Stocks (n / night fyke)		Length (cm)	
	2009	2011	2009	2011	2009	2011
target spieces						
Eel (red)		16		0,41		59-80
Eel (silver)		85		2,15		68-100
Other spieces						
Perch	3847	53114	769,4	1344,66	9-21	7-31
Roach		7821		198		7-22
Bream		3260		82,53		6-20
Silver bream		1		0,03		15
Ruffe	350	12612	70	319,29	10-21	6-14
Rudd		77		1,95		9-14
Pike-perch	10	341	2	8,63	11	12-19
Total	4207	77327	841,4	1957,65	9-21	6-100
number of target sp	0	2				
Number of other spi	3	7				

Table 18 *Catch results per species in the trapping structure behind the Kralingse Plas pumping station in the autumn of 2011 and during the baseline measurement in 2009.*

Spieces	Number of passers		Passers night fyke		Number damaged		Percentage damaged		Length (cm) unscathed		Length (cm) damaged	
target spieces	2009	2011	2009	2011	2009	2011	2009	2011	2009	2011	2009	2011
Eel (silver)	19	3	3,8	0,6	19	0	100	0		72-76	60-78	
Other spieces												
Perch	1323	17376	264,6	3475,2	423	7	32	0,04	10-12	7-24	10-12	6-10
Roach		915		183		0		0		8-24		
Bream		1892		378,4		6		0,32		6-23		6-9
Silver bream		1		0,2		0		0		16		
Ruffe	121	6843	24,2	1368,6	0	2	0	0,03	10	6-10		8-9
Pike-perch	40	15	8	3	0	0	0	0	11	12-17		
Orfe		3		0,6		0		0		14-16		
Total	1503	27048	300,6	5409,6	442	15	29,4	0,06	10-12	6-76	10-78	6-10
number of target spiec	1	1										
Number of other spiece	3	7										

Table 19 *Capacity at which the Kralingse Plas pumping station operated during the passage determinations in the autumn of 2011, related to the total number of fish having passed per net raising.*

Net raising	Running time (min)	Flow (M³/min)	Total water (m³)	Total fish (n)	n/10000 m³
1	240	30	7200	866	623,5
2	240	30	7200	11448	8242,6
3	90	30	2700	415	112,1
4	300	30	9000	7807	7026,3
5	180	30	5400	6512	3516,5

Throughout the entire research period in 2011 perch was by far the largest catch in the stocks fyke nets, followed at a distance by ruffe, roach and bream (Table 17). This mainly concerned small perch of 8-9 cm in length. During the baseline measurement in 2009 the stocks were limited to perch, ruffe and a small amount of pike-perch. The absolute numbers of this last species were greater in the relevant catches in 2011 than in 2009, but relatively speaking far fewer (in respect of the distribution with the other species). The lengths of the scaly fish are comparable year-on-year, even though the pike-perch seems a little larger in 2011. Although the relative numbers of eel almost disappear as compared to the very large number of perch, 101 specimen of this target species were caught, including 85 silver eels with a length ranging from 68 to 100 cm. During the baseline measurement not a single eel was caught.

During the passage determinations in both years to a large extent the same species were caught in the same proportions in the stocks fyke nets and behind the pumping station (Table 17 and 18; Figure 28). In 2011 no rudd was caught behind the pumping station although present in the stocks in low density. Orfe was only present in very low numbers in the trapping structure behind the pumping station. In 2009 nineteen silver eels were caught behind the pumping station (3.8 per night fyke) whereas this species was missing in the stocks fyke nets. This number was high as compared to 2011 (three specimens in total, 0.6 per night fyke).

In order to research whether the number of passers depends on the output of the pumping station, per passage determination the total turning time and the flow were plotted against the catch (Table 19). No relation can be established between the flow and the total number of passers per raising of the fyke nets. The number of fish caught appears to increase with the total amount of water that has flowed through the pumping station during a passage determination.

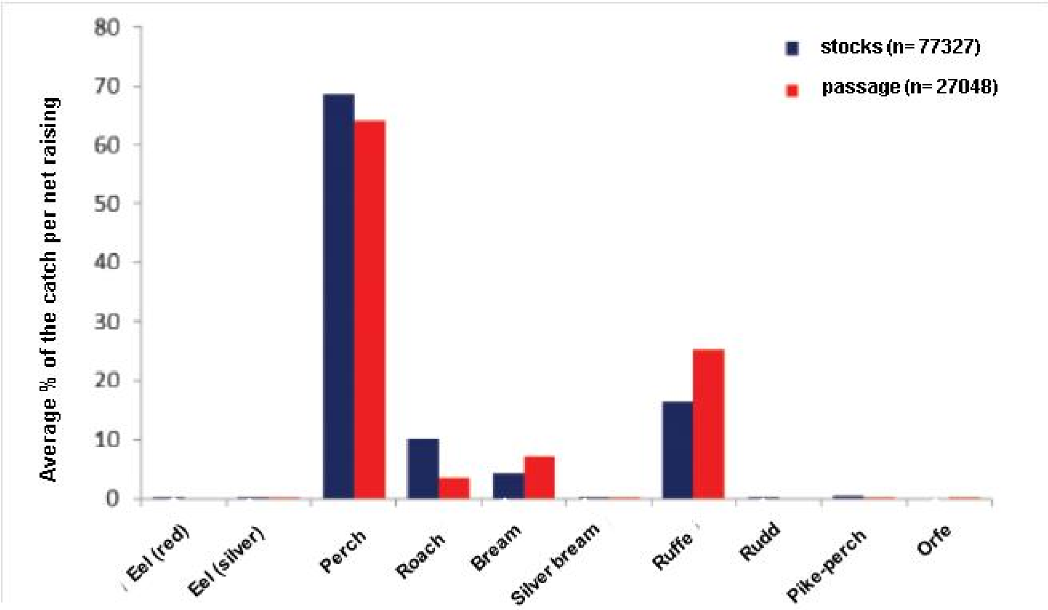

Figure 28
Relative abundance per species in the stocks and passage determinations near the Kralingse Plas pumping station in the autumn of 2011.

4.3 Sound Emission

4.3.1 Question 6 – Can low noise solutions contribute towards reducing the barrier effect of pumping stations?

The noise was measured at the Krimpenerwaard, Kralingse Plas, Aalkeet Buitenpolder and Hoekpolder pumping stations during the baseline monitoring in 2009. This paragraph first summarizes the results for the non-adapted Krimpenerwaard and Aalkeet Buitenpolder pumping stations. Subsequently, the results of the measurements performed in 2011 near the new pumping stations Hillekade, Kralingse Plas, Hoekpolder and Ennemaborgh are discussed and where possible they are compared to the measurements for their predecessors in 2009.

Kralingse Plas Pumping Station
In the funnel-shaped access to the pumping station there were noise levels in the 2-5000 Hz frequency bandwidth with the pump deactivated between 110 and 118 dB re 1 μPa average (Table 34). In the 100-300 Hz and 900-1200 Hz frequency bandwidth the values are respectively around 80 and 90 dB re 1 μPa (Table 34). The activation of the pump resulted in a minor increase in the sound levels at a distance of 2 m in the bandwidths we examined: 4 dB for 100-300 Hz and 6 dB for 900-1200 Hz. At greater distances absolutely no increase in the sound level in these bandwidths could be attributed to the activation of the pumping station (Table 34). The outflow of the pumping station is located in a fairly shallow place, thus generating considerable current. In connection with this we found a major increase in the sound level when the pump was activated for the 2-5000 Hz 19 dB frequency bandwidth for the 100-300 Hz 33 dB bandwidths and for bandwidth 900-1200 Hz 31 dB.

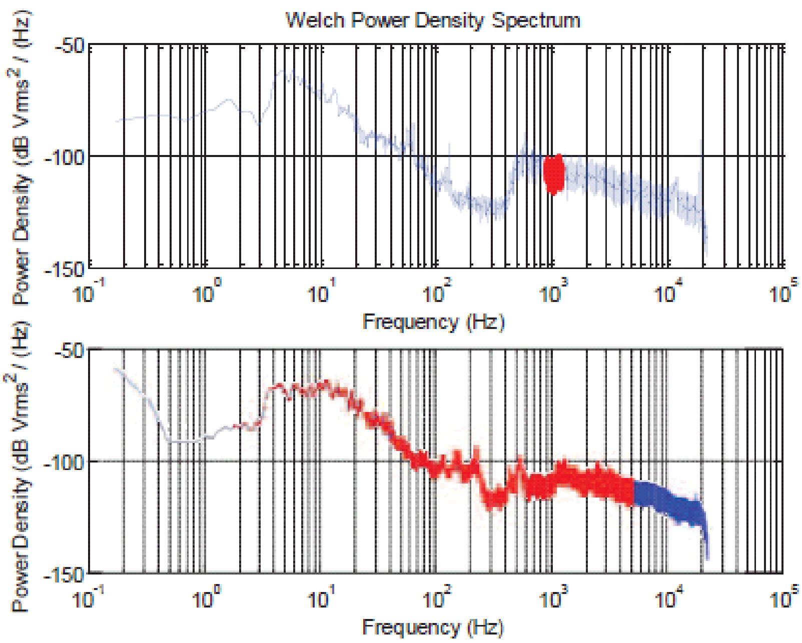

Figure 43
Sound spectra at the Kralingse Plas pumping station with the pump deactivated at 2 m from the inflow, with the new measurement (December 2011) at the top and the old measurement (May 2009) at the bottom. Reddening of the various frequency bandwidths (900-1200 and 2-5000 Hz) is not functional in this figure or in the following figures.

Table 34 *Sound levels at the Kralingse Plas pumping station for three bandwidths at four distances on the lake side and at the outflow at the Rotte (average of four repeated measurements). 'ON' = pumping station pump activated; 'OFF' = pumping station pump deactivated.*

Distance (m)	Sound level (dB) 2-5000 Hz		Sound level (dB) 100-300 Hz		Sound level (dB) 900-1200 Hz	
	On	Off	On	Off	On	Off
2	109,6	111,2	76,8	80,8	89,7	95,7
14	115	115,2	81	77,4	90,6	91,8
32	117,7	121,5	81,1	87	89,8	89,1
100	113,2	113,2	80,6	86	89,9	88,8
Discharge	111	129,8	84,1	117,3	79,5	111,3

In 2011 the axial flow pump of this pumping station was replaced with a fish friendly version. Measurements were also performed in May 2009 prior to the replacement, thus allowing a comparison. If we first consider the sound spectra with the pump deactivated (Figure 43), we notice that both measurements are a good match. In 2009 slightly more noise was recorded in the 100-300 Hz frequency bandwidth, which could possibly be attributed to ongoing boat traffic or dredging activities on the lake.

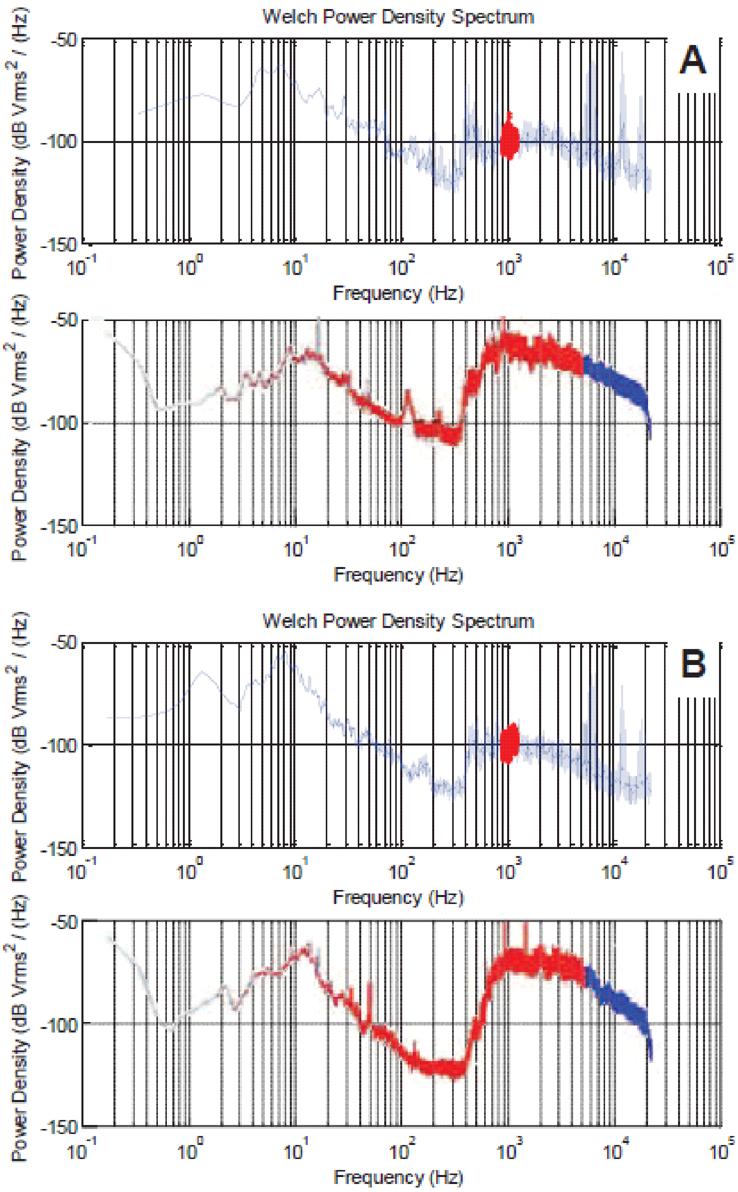

Figure 44
Sound spectra at the Kralingse Plas pumping station with the pump activated at 2 m (A) and 14 m (B) distance from the inflow, with the new pump at the top and the old pump at the bottom.

When the pump was activated in 2009 there was no major increase in the sound level (Figure 44). The greatest increase was noted in the relative high-frequency sound component, i.e. in the measurement in the 900-1200 Hz bandwidth and in the sound spectra (Figure 44). The sound levels decreased with distance, but there was a major increase in the noise in the whole funnel-shaped access to the lock door and the suction inlet of the pumping station pump. The increase in the 900-1200 Hz bandwidth was particularly striking: 39.1 dB at 2 m of the inflow, 31 dB at 14 m and still 6.1 dB at 32 m (no measurement was performed at 100 m). The new axial flow pump is consequently very quiet as compared to the old pump. A study of the sound spectra shows that the pumping station did generate noise around 6500 Hz and above 10 kHz (see Figure 44), but that these noises are not audible to Dutch freshwater fish.

4.4 Pump Efficiency

4.4.1 Question 7 – What is the pump efficiency of the fish safe innovative pumps?

At the Hillekade, Kralingse Plas, Hoekpolder and Ennemaborgh pumping stations fish friendly elevation works were chosen as adaptation to reduce the damage percentages and the barrier effect for fish. Research into the pump efficiency is a useful parameter to determine what these adaptations can represent for the functioning of the pumping station as a polder drainage system and as a fish passage. The water manager requires the highest possible pump efficiency in order to be able to drain a polder profitably. It should be noted that on the whole the pump efficiency increases with the flow and that passing fish are more frequently damaged at high speeds (see comparison between the distinct situations in 2011 for the Aalkeet Buitenpolder pumping station, but this is greatly dependent on the design).

The best possible solution for the water manager and the fish is a pumping station that offers a fish safe passage option at high speed (and high efficiency). For the pumping stations in which the old and new situation can be compared, i.e. Kralingse Plas and Hoekpolder, the solution is successful. Both new elevation works have an efficiency of circa 82%. The pump efficiency in the old situation was 70 – 72% for the Kralingse Plas pumping station and 60 – 65% for the Hoekpolder pumping station.

For the Hillekade, Kralingse Plas, Aalkeet Buitenpolder and Hoekpolder pumping stations we researched whether the speed (expressed as the flow in m^3/min) is related to the number of fish passing the pumping stations (see Table 16, 19, 22 and 24). As the number of passage determinations was limited and some pumping stations always operated at the same output, no statement can be made. In most instances it appears that the number of passing fish does increase with the total amount of water pumped through the pumping station during a sampling night. Here also the limited sample size does not produce significant results.

Based on the non-significant results we can merely state that the data seem to indicate a better passability of the pumping stations given a higher flow.
Current research does however demonstrate that the fish friendly pumping stations also guarantee fish safety at high flow.

Summary

The decision to opt for adapted pump operation instead of the use of an adapted pump, as described for the Aalkeet Buitenpolder pumping station, produces lower efficiency for increased fish safety. The efficiency of the new fish safe elevation works is equal to (Hillekade, Kralingse Plas and Ennemaborgh) or greater (Hoekpolder) than the output of the old elevation works. As the fish can pass the new pump operating at high speeds with a very low damage percentage, here high pump efficiencies go together with good fish passability and fish safety.

Contribution to the WFD Objectives

4.4.2 Question 8 – What is the effect of the facility on the EQR score of the WFD water body?

Kralingse Plas Pumping Station

Inside

The Kralingse Plas water body is of WFD water type M14. Before the adaptation of the pumping station the WFD assessment was: insufficient, EQR=0.22 (Spier *et al.* 2007; Maessen *et al.* 2008). On the partial scaling the number of species (excluding alien species) scored EQR=0.27. The weight share of bream, a negative indicator, scored EQR=0.17, the weight percentage of phytophilic species EQR=0.19, the weight share of oxygen tolerant species 0.00 and the weight share of perch and roach on the eurytope species EQR=0.46.

The new pumping station will obviously raise the general evaluation for the Kralingse Plas. The outward migration options created for diadromic species do not have a negative effect on the EQR score, as the number of migrating species is not considered in this scaling. The monitoring did confirm that eel use the pumping station for their outward migration. Some gain could be recorded on the partial scaling that assesses the weight share of bream. The autumn data of 2011 show that a lot of bream passed through the pumping station. The magnitude of the effect cannot be estimated on the basis of the existing data.

Outside

The Rotteboezem water body is also of WFD water type M14. Before the construction of the new pumping station the WFD assessment was: insufficient, EQR=0.29 (Broeckx *et al.* 2011). On the partial scaling the number of species (excluding alien species) scored EQR=0.90. The weight share of bream, a negative indicator, scored EQR=0.15, the weight percentage of phytophilic species EQR=0.21, the weight share of oxygen tolerant species 0.00 and the weight share of perch and roach on the eurytope species EQR=0.21.

The improved fish passability through the new pumping station may raise or lower the general evaluation for the Rotteboezem. The return migration options created from the Kralingse Plas for diadromic species had a positive effect on the EQR score.

The monitoring confirmed that eel use the pumping station for their outward migration. A lower score on the partial scaling that assesses the weight share of bream seems probable. The autumn data of 2011 show that a lot of bream passed through the pumping station. The magnitude of the effect cannot be estimated on the basis of the existing data. A positive effect is expected on the partial scaling related to the weight share of perch and roach on the eurytope species. More specifically, perch passed in huge numbers through the pumping station to the Rotte in het autumn of 2011.

Table 37 Comparison of the EQR scores before and after the adaptation of the pumping stations. Adaptation of the pumping stations Krimpenerwaard and Verdoold has been postponed; they are not included in the VZWHEW project.

Pumping station / Lock	EQR before adaption		EQR after adaption	
	Inside	Outside	Inside	Outside
Krimpenerwaard	Adaption of this pumping station is postphoned			
Verdoold	Adaption of this pumping station will be in 2013			
Hillekade	0.71	0.72	±	±
Kralingse Plas	0.22	0.29	+	- or +
Abraham Kroes	1.00	0.95	±	±
Snelle Sluis	0.95	na [1)]	±	na [1)]
Aalkeet Buitenpolder	0.52	0.50	+	±
Hoekpolder	0.2-0.4	0.89	+	-
Maelstede	0.46	? [2)]	+	±
Ennemabrogh	0.49	0.50	±	±

- = decrease; ± = equal; + = increase

[1)] To the best of our knowledge the part of the Hollandsche IJssel located here is not a water body.

[2)] The EQR of the Westerschelde is not known; presumably the adaption has no effect.

6 Conclusions and Recommendations

6.1 Conclusions

6.1.1 Fish safety and Fish Passability

Share that migrates via the pumping station pump

Mainly the eurytope fish category uses the route via the pumping station. Initially the share that follows this route varied (from ‘relatively small’ to ‘relatively large’), but after the adapted civil engineering works it appeared to be ‘relatively large’ everywhere.

Some limnophilic species seem to avoid passing through the pumping station pump and some rheophilic species actively migrate through the pumping station pump. For the target species, more specifically eel, the results are less obvious because the caught numbers of these species are generally low.

Suitability of the Bypass as a Migration Facility

De overfall fishways (installed near the Abraham Kroes, Aalkeet Buitenpolder and Maelstede pumping stations) operate alongside the pumping stations, but not yet optimally. The fish pass the bypasses without damage, but a greater share seem to prefer the pumping station pump as a migration route to the bypass when the pumps are active.

Percentage of Fish Damage for Adapted Pumping Stations

Fish damage occurs in all adapted pumping stations, but the percentage is of less than 5% in all the investigated cases and in most cases is less than 1%. The damage percentages per pumping station and fish group are significantly lower after the adaptation than before the adaptation.

The other innovative facilities (bypasses) do not on the whole cause any perceptible damage to fish, nor do the fish friendly screens through the Snelle Sluis (Quick Lock).

No relation could be demonstrated between the damage percentage and the fish length with regard to scaly fish for any of the pumping stations with adequately large catches. With some degree of caution the damage percentages presented can be considered valid for the entire length range of a species. We submit this reservation because near the Hoekpolder pumping station the percentage of damage cases did increase up to a length of 15 cm (to 5.1%), when the data was grouped to broader length classes. Above this length all the fish passed through the pumping station unscathed.

Increased Fish safety and Fish Passability Thanks to the Axial fish friendly pump

The use of a axial fish friendly pump in the Kralingse Plas pumping station resulted in a considerable drop in the damage percentage to fish, including eel. Based on this finding we can expect that the axial fish friendly pump will have a positive effect on fish safety and fish passability of a pumping station.

Increased Fish safety and Fish Passability Thanks to the Fish Friendly Screw Conveyors

The monitoring of the Hillekade and Hoekpolder pumping stations shows that a large share of the fish stocks, including target species, uses the screw conveyors as a migration route. After the installation of the screw conveyor in the Hoekpolder the damage percentage dropped significantly and, just as for Hillekade, it is very low today. This allows us to conclude that the use of these fish friendly screw conveyors can increase fish safety and fish passability through pumping stations.

Increased Fish safety Thanks to the Adaptation of Pump Management, Intake Management and Lock Management

By operating the Aalkeet Buitenpolder pumping station, which was not made fish friendly, at a lower speed than usual, the fish passability and fish friendliness were clearly increased. At minimum speed over four times as many fish passed per night fyke than at normal speed. Moreover, the damage percentage for the total scaly fish catch at minimum speed of the pumping station pump was more than a factor lower than the damage percentage at normal speed (respectively 0.36% and 4.78%). The fish friendly lock management in the Snelle Sluis, has shown that this management can contribute greatly to the unhindered and safe outward migration in the spring and autumn. Also the silver eel and yellow eel target species appeared to be able to move outwards against the current.

6.1.2 Sound Emission

Reduced Migration Barrier through Low Noise Solutions

The results do not allow us to conclude that a low noise pumping station reduces the barrier effect for migrating fish. In spite of the sound emission at frequencies audible to fish near two researched pumping stations, a large share of the stocks of eurytope species and variable stocks of rheophilic, limnophilic and diadromic species passed through the pumping station. The only low noise pumping station (Kralingse Plas) displayed a higher number of passing other species and a lower number of passing target species after the adaptation. The cause of this lower number is not known, but coincidence, weather conditions or a drop in the eel population in the Kralingse Plas cannot be excluded.

6.1.3 Pump efficiency

Pump efficiency of Innovative Pumps

The efficiency of the new fish safe elevation works is equal to (Hillekade, Kralingse Plas and Ennemaborgh) or higher (Hoekpolder) than the efficiency of the old elevation works. Because of the positive relation with the flow, the efficiency drops when the pumps run at low speed. As the fish can pass through the new pumps with a very low damage percentage it is not necessary to operate the pumps at lower speeds for fish migration.

6.1.4 Contribution to the WFD Objectives

Effect of the Facilities on the EQR score

For four of the eight researched civil engineering works there could be a possible increase in the EQR score in the hinterland (the ‘inside’ of the lock or pumping station) as a result of improved fish passability.

For four of the eight researched civil engineering works the implemented improvements are not expected to increase the EQR score in the hinterland. Here the score for phytophilic and migrating fish species is already at a maximum level, or an improved inward and outward migration of diadromic fish has no effect on the scaling score. However, in a number of instances a possible gain could be obtained due to a higher outward migration of bream and carp.

No improvement of the EQR score is expected for any of the eight researched civil engineering works of the water body in which the civil engineering works drains. In most instances the number of phytophilic and migrating species in the receiving water is at a maximum.

6.2 Recommendations

6.2.1 Fish safety and Fish Passability

As yet it is not possible to measure the efficiency of the overfall fishways properly. Near the Abraham Kroes and Aalkeet Buitenpolder pumping stations more fish seem to be passing through the pumping stations than via the fishway. To improve the operation of the bypasses in this respect, the planned fishways for these pumping stations must be fitted.

The outward migration should still be monitored at the Maelstede pumping station. After a familiarization period of a few years for the fish, all fishways should be investigated to determine whether the fish have discovered the alternative route.

The limited catch near the new Ennemaborgh pumping station did not allow to accurately determine the effectiveness of this pumping station as a migration route for fish. Therefore a repetition of the stocks and passage research is recommended in the coming years.

To increase the overall catches during monitoring research it is recommended to develop more flexible methods allowing to anticipate periods of unfavourable weather conditions for fish migration.

As the relation between the size of the fish stocks and the number of passers cannot be directly established, further research focusing on following individual fish is recommended. To this end fish monitoring with transmitters could be considered.