N°15
APRIL 2012

ONEMA
MEETINGS

Management plan to save the eel
Optimising the design and management of installations

The Eels & Installations R&D programme is the result of a partnership between Onema, Ademe and five hydroelectric companies. Over the past three years, the programme launched 18 research projects to optimise the design and management of installations to protect migrating eels. On 28 and 29 November 2011, the feedback symposium brought together 160 persons, including researchers, water managers, associations and hydroelectric companies, in the conference room of the Porte Dorée aquarium in Paris. This key event in the French eel-management plan sketched a panorama of the results achieved in a series of presentations addressing the operational aspects of issues. The presented solutions and tools pave the way for a collaborative response by the economic participants to the challenge of restoring the species.

The European eel is an emblematic species in European rivers. Over the past 30 years, it has suffered a severe drop in numbers due to a series of anthropogenic pressures including water and sediment pollution, habitat degradation, overfishing and poaching, hydropower turbines and obstacles to its colonisation of rivers and to its downstream migration.

A silver eel.

The R&D programme is a regulatory necessity for an ecological crisis

Eels are considered endangered by the International union for the conservation of nature (IUCN) and in 2007 the European Union voted a regulation (EC 1100/2007) requiring the Member States to adopt restocking measures targeting (article 2.4) a return to the quantity of adult-eel biomass that existed prior to 1980. In France, this pro-active policy resulted in the decision to launch a management plan to reduce catches by 60% by 2015 and other causes of mortality (including those caused by installations blocking rivers) by 75% by 2018. This goal led the Ecology ministry to prepare an R&D programme on installations blocking rivers, comprising a coherent set of 18 research projects carried out from 2009 to 2011 in the framework of a partnership between Onema, Ademe and five hydroelectric companies, namely Compagnie nationale du Rhône, EDF, France Hydroélectricité, GDF Suez and Société hydroélectrique du Midi.

A mysterious life cycle between the Sargasso Sea and inland waters

The Sargasso Sea, in the North-western Atlantic, is the only known spawning zone for the species. Eels begin as transparent larvae, 5 to 10 mm long, called leptocephali, that become glass eels (75 mm) one to three years later, depending on the hypothesis considered, when they reach the European continental shelf toward the end of the summer. They enter estuaries and migrate to inland water bodies. In the process of growing, they become yellow eels and settle in highly diverse environments (rivers, marshes, isolated ponds, etc.). Sexual differentiation occurs when the fish are about 20 cm long, with the males primarily in coastal zones and the females upstream.
Once they have finished growing, the yellow eels become silver eels and can exceed one metre in length. Following a heavy rainfall, often in the fall, the silver eels race down the rivers to the sea and migrate 5 000 km across the ocean to the spawning grounds in the Sargasso Sea.
This life cycle still harbours many mysteries, notably the factors determining the zones colonised, sexual differentiation and reproduction.

Tidal doors and floodgates regulate the movement of water in estuaries.

Upstream migration, installations, their effects and technical solutions

To restore eel biomass, an essential first step is to facilitate the access of glass eels to inland waters. Even before they can reach the rivers, their travel, which depends on the tides in estuaries, is blocked by a large number of installations (tidal doors, valves, floodgates, etc.) established to control the flows of fresh and salt water between estuaries and inland waters. One project in the R&D programme (Ch. Rigaud, Irstea, Ph. Baran, Onema) established a typology of the installations and determined the biological effectiveness of systems designed to allow, in winter, a regular inflow of limited volumes of salt water. Eight sampling campaigns were carried out on tidal doors, on the Charras site (the estuary of the Charente river), that were equipped with a 10 cm chock to inhibit complete closing of the doors. The entering glass eels were collected every 20 minutes by a filter system. The campaigns produced useful results concerning different aspects of the passage of the fish (e.g. the time before or after high tide, nyctohemeral rhythms, passage under or over the doors) and confirmed the effectiveness of the system for upstream migrations. However, each installation raised specific problems. Operational management must be approached on a case-by-case basis, targeting the most important installations in terms of their effects. Management must notably take into account the acceptable water volumes given the upstream constraints.

Philippe Goetghebeur,
Rhine-Meuse water agency

Do not neglect maintenance on existing installations

«In terms of funding the various projects, we are now at a crossroads. For the next four or five years, the projects concerning fishways represent virtually the entire budget allocated for environmental-management operations. It will thus be necessary to set priorities, sector by sector and river basin by river basin, with all the various participants and all the organisations involved. Cost effectiveness will be a critical parameter in determining priorities. In addition, regular maintenance is essential to ensure system effectiveness.»

Similar to the above study, efforts undertaken to assess the passage rate of an installation equipped with a special type of fishway (brush pass) commonly encounter the difficulty of precisely determining the number of eels arriving at the downstream entry point of the fishway. As part of the R&D programme (Ch. Rigaud, H. Drouineau, Irstea, Ph. Baran, Onema), coloured visible implant elastomer (VIE) tags were used on elvers (< 15 cm) to evaluate the accessibility and the «passability» of three installations, located near the high-tide line and equipped with special brush passes. Tagged specimens were released at the foot of fishways (also called fish passes) or downstream of obstacles. The tagged individuals caught in pass-traps provided valuable information on when glass eels start their migration, a factor that varies significantly between sites and even within a given site.

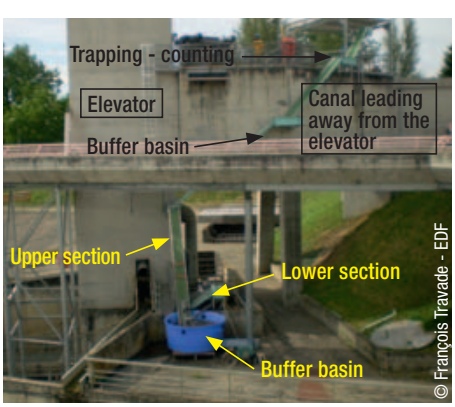
Once the tidal installations have been overcome, large dams constitute a second type of obstacle for upstream migration. «Brush passes» or passes with artificial substrates have for years been installed at certain installations to enable elvers to travel upstream. That is the case at the EDF dam in Golfech where several configurations of ramps with low flow rates have been created since 2002 to overcome the obstacle that is 20 metres high. A research project (L. Carry, Migado, F. Travade, EDF R&D) validated in situ a new configuration including an intermediate «buffer basin» to prevent travel back downstream. The study, carried out over three migration seasons from 2008 to 2010, counted the elvers travelling through the system and monitored the progression of individuals marked with pit tags.

Anne Pénalba,
France Hydro Électricité

Hydroelectric companies will not be able to pay for the necessary investments

«The research programme cleared up numerous points. The diagnostic criteria for entire rivers, which did not exist three years ago, represent a fundamental step forward in our opinion. We now have the numerical data required to calculate costs, for example that of adding a «fish-friendly» water intake. Unfortunately, no miracle solutions have been found. Each technical solution is costly and difficult to implement. For the future, we recommend the standard approach. Once we have a solid diagnosis agreed upon by all participants, any measures will have to be judged on the basis of a cost-benefit analysis. The remaining problem will be the funding because hydroelectric companies will not be able to pay for the necessary investments.»

This type of fish pass with an artificial substrate demonstrated its effectiveness for tall obstacles and a number of important improvements were made, including adding the basin in the lower section to prevent return travel, a device to facilitate exit of the eels upstream and protection against predation by birds. In



Eel pass at the Golfech dam (Garonne river).

addition, a related project (F. Travade, EDF R&D), on the same site, developed and tested an automatic system to count and calibrate elvers sliding through four tubes equipped with electrodes and located at the top of the fish pass. The system implements a resistive counter, designed by ELFES-ELTA, that detects changes in resistivity when the fish pass near the electrodes. The system provides precise biological information on individuals at least 125 mm in length. Adaptations to the system should make it possible to monitor glass eels and elvers smaller in size.

Capture of an eel after its passage through a turbine.

Downstream migration and impacts on hydropower turbines

During the return of silver eels to the sea, hydropower turbines represent a significant risk of mortality. Even when downstream bypasses exist, some of the adult fish go through the turbines. To improve stock management, it is indispensable to evaluate injury and mortality rates caused by the various types of turbines used in hydropower plants. This type of evaluation (E. De Oliveira, EDF-LNHE, F. Pressiat, CNR) was carried out on large turbines often found along the Rhine and Rhône rivers (Kaplan turbines with 4 or 5 blades, bulb turbines). The project protocol used in Fessenheim and Ottmarsheim on the Rhine river and in Beaucaire on the Rhône river implemented a standard marking and recapture technique with HI-Z Tag inflatable tags. A group of large eels was released at different points just upstream of the turbines and then recaptured downstream of the hydropower plant. The results, shown in the table below, indicate the percentage of fish that survived after one hour and after 48 hours.

In addition, an analysis of Kaplan turbines was carried out based on data from experiments run on 24 sites in Europe and North America (P. Gomes, M. Larinier, Onema). This analysis revealed highly variable mortality rates depending on the sites. Mortality increased with the size of the eels and the rotational speed of the turbines, and decreased for smaller turbine diameters and lower nominal flow rates. Mortality rates ranged from 5% to 10% for large, low-head turbines and exceeded 80% for some small turbines with high rotational speeds. An in situ study on small Kaplan turbines must still be carried out and for the time being, the data is drawn from the literature. Following the analysis, the research team produced equations to predict mortality rates as a function of eel size, rotor diameter, the nominal flow rate and the rotational speed.

Gilles Crosnier,
EDF, Water-environment management South-West

A compensation system covering entire river basins?

«The R&D programme has put us in a position to save time and not dissipate our efforts. A few solutions that failed to show results were eliminated (infrasonic repulsion, Migromat), whereas the tools for entire rivers constitute an essential contribution for setting work priorities. With those tools in mind, would it not be possible to imagine a financial compensation system for entire river basins? Instead of investing money in a project with low prospects for success, it could be invested elsewhere much more effectively. This is a matter that should be looked into!»

Understanding the effects of turbines and of the installations themselves

The data obtained on turbines are not sufficient to estimate the overall mortality caused by an installation. It is necessary to characterise the behaviour of eels when confronted with different means of overcoming installations (turbines, locks, dams, bypasses). A three-year study (F. Bau, Irstea, F. Travade, EDF) was carried out on the lower Gave de Pau river where 192 silver eels were equipped with emitters and monitored by radio over a 60-kilometre section comprising six hydropower installations.

Plants	Characteristics of turbines and installations			Survival rate		Injury rate	Percentage of uninjured individuals
	Diameter	RPM	Head	1 hour	48 hour		
Fessenheim Kaplan 4 blades	6.67 m	88.2	15.7 m	93.2 %	92.4 %	11.5 %	92.6 %
Ottmarsheim Kaplan 5 blades	6.25 m	93.7	15.5 m	82.6 %	78.6 %	27.6 %	75.5 %
Beaucaire Bulb 4 blades	6.24 m	94	16 m	95.6 %	92.3 %	6.8 %	91.6 %

Mortality rates in large turbines (E. de Oliveira, EDF R&D, F. Pressiat, CNR).

François Travade, EDF R&D

Make use of the initial feedback

«This R&D programme was necessary given our insufficient knowledge worldwide on how eels can overcome obstacles. The programme enabled us to make progress in diagnosing impacts and concerning possible solutions. Of course, these solutions must be adapted to each hydropower plant. Such a «tailored» approach, very common in the empirical science of fishway engineering, must absolutely take into account the feedback from initial projects. It is critically important to evaluate the functionality of the initial systems created and to apply the knowledge gained to subsequent projects.»

Antennas installed at each installation informed on the time of passage and, above all, the paths followed by the eels given the configuration of each installation, in conjunction with a number of other parameters acquired on each site (hydrology, conductivity, temperature, etc.). A majority of the fish passed via the spillways (68% on average), with significant discrepancies depending on the general configuration of the spillway and the spaces between the bars of the water intakes. Tools were proposed to estimate escapement rates as a function of hydrological conditions, flow rates at the water intakes and the configuration of installations.

A similar approach based on the NEDAP technology using RFID (radio-frequency identification) was implemented on the French side of the Rhine to see how eels overcame a series of six obstacles equipped with detection systems (long underwater antennas) (E. de Oliveira, EDF-LNHE). During the first two years, the experiments suffered from numerous technical problems that have since been solved. Though expensive and difficult to implement, this technique should inform on the paths followed by the fish in overcoming the obstacles and, using the mortality equations for each type of turbine, make it possible to estimate not only the number of eels travelling downstream and succeeding in overcoming the installations along the French section of the Rhine, but also the time taken by each individual, which can vary considerably. For this project, the plan is to equip and release over 300 eels each year over the next four or five years.

Understanding the effects of installations and series of installations

This new knowledge on downstream-migration rhythms and on the behaviour of the fish in and around installations has made it possible to evaluate the cumulative losses caused by a series of installations along a river. This type of evaluation is a necessary step toward integrated management of entire river basins (P. Gomes, M. Larinier, Ph. Baran, Onema). Using the results and models produced for the Gave de Pau river, a downstream-migration model was created for a series of characteristic flow rates, i.e. during the migratory period, the eels are divided equally among the flow rates considered characteristic (Q75, Q90, Q95, Q97.5 and Q99). This model was enhanced with statistical models on flow rates at turbine intakes and with the mortality equations for each type of turbine (see figure 1). This new method, the only one validated to date, provides for a given period a percentage of escaping eels for each installation and an overall percentage of eels surviving all the installations. When applied to a river in south-west France comprising 26 installations, the model indicated an overall percentage of escaping eels between 33% and 66%, with an average of 49%.

Turbine management to reduce mortality rates

In addition to these efforts to diagnose the situation, the R&D programme looked a different means to reduce mortality rates caused by the turbines. One obvious solution is to halt generation during peak migration periods, but this is very expensive in terms of energy production. To time the stops in production as best possible, managers must be in a position to anticipate, for a given river, the time periods when the largest numbers of fish are underway. The MIGROMAT® biomonitor, designed specifically for this purpose, analyses the movements of silver eels equipped with transponders and held captive in basins supplied with river water. The eels react to changes in water characteristics, thus signalling by their enhanced activity that downstream migration is likely. This system, marketed

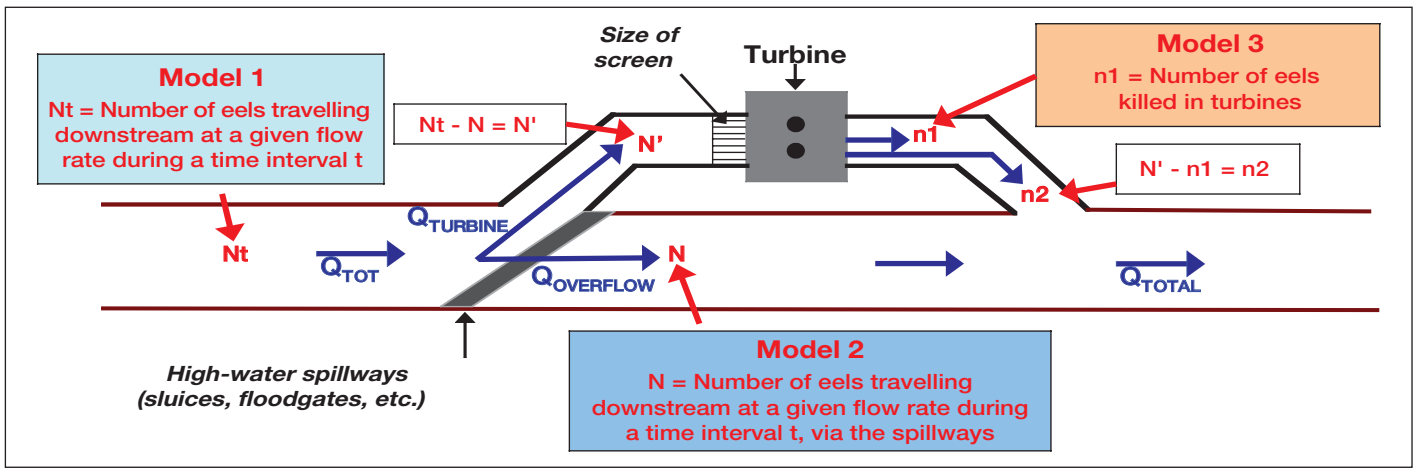


Figure 1. Cumulative losses for a series of installations by combining predictive models for one installation.

by a German engineering firm, was tested (T. Kieran McCarthy, R. McNamara, Galway University) from September 2008 to March 2010 in Killaloe on River Shannon (Ireland).

The research project compared the alarms issued by MIGROMAT® and the migratory peaks measured by a nearby fishery. The results showed that the system, in its current form, is not very effective. The alarms generally corresponded to peaks in migratory flows, but were issued too late. On the whole, the opinions of professional fishermen proved better in predicting the downstream migration of eels.

Another experiment, requiring more resources but producing better results, was run on the Dordogne river (L. Lissalde Bonnet, EDF CIH). A sampling system, comprising a floating platform equipped with a «guideau» net spanning a fraction of the water channel (10% in this particular experiment), was tested in the flume supplying the Mauzac hydropower plant. The system caught 214 eels during 140 fishing nights (from 1 September 2009 to 26 January 2010). Its effectiveness was confirmed by a tagging and recapture operation during which 8% of the tagged eels were caught by the net, a percentage comparable to the netted portion of the flume. Though well suited to acquiring information on downstream-migration rhythms, this system is expensive and occupies two people full time for four to five months. In addition, its use is limited to channels that are fairly narrow (the net must cover a significant fraction) and have sufficient flow rates to ensure effective catches.

To set up true power-generation management programmes on a large scale, operational, predictive models are an indispensable first step. Such a model (A. Acou, MNHN) was developed for the Loire river between the cities of Angers and Nantes. The Loire is the only river in France for which long-term data series on catches are available. The research team linked the catch data series with various environmental parameters, e.g. daily variations in flow rates, water turbidity, luminosity index and weather conditions. The final model, based on 20 years of data, was designed to predict downstream-migration periods 24 hours in advance. It provides fairly robust results in that 80% of the peaks in effective catch rates are predicted. Simulated halts in electrical generation in the study zone confirmed the superior results of this model in terms of escapement rates compared to methods based exclusively on threshold flow rates.

These gains in knowledge provide the necessary quantitative basis to launch discussions between the hydroelectric sector and public authorities. Management of hydropower generation must now be approached from an economic angle. The initial comments during the final round table during the symposium confirmed that acceptable halts in generation will have to be determined on a case-by-case basis, taking into account rigorous cost-benefit criteria.

Zéphyre Thinus, DREAL (Regional environmental agency), Haute-Normandie department

We are in favour of «fish friendly» water intakes

«The regional environmental agency took part on the planning level in the diagnosis carried out by the departmental territorial agency in the field to save the eel. In the Haute-Normandie department, with its numerous small, coastal rivers, it is difficult to simply stop the turbines. On the 20 sites located in priority action zones, we are in favour of creating fish-friendly water intakes. Existing screens are generally positioned at favourable angles and a reduction in the distance between the bars would suffice. We recommend starting this work on rivers involving the lowest costs. For the other rivers, we must first improve the models.»

Additional approaches with «fish friendly» turbines and water intakes

In addition to generation management, a number of other technical solutions were proposed and tested in the R&D programme. Further development work is of course needed. One solution is «fish friendly» turbines and particularly the VLH (very low head) turbine (see the photo) designed for 1.4 to 3-metre heads and that can be adapted to some existing structures. An initial prototype was tested successfully in Millau during downstream-migration tests on smolts and silver eels. After a few dimensional adjustments, the new VLH turbine was put through extensive tests in Frouard on the Moselle river (M. Leclerc, MJ2/ECOGEA), where it produced a maximum of 400 kW for a net head of 2.4 metres and a flow rate of 22 cubic metres per second. The experimental results were most promising with a percentage of lethal injuries close to zero and non-lethal injuries within 48 hours of approximately 2%. The R&D programme (F. Travade, EDF R&D) also contributed to the industrialisation procedure for another, very different «fish friendly» turbine, the ALDEN turbine developed by the Alden hydrological lab in the U.S. This turbine, for which Voith Hydro carried out the final development work from 2008 to 2010, is 3.7 metres in diameter and optimised for a flow rate of 45 cubic metres per second with a head of 28 metres. According to the models, the survival rate should be 98% for fish up to 200 mm long and 100% for fish 100 mm long. In situ tests for eels of sizes corresponding to those migrating downstream will be carried out in 2014-2015. However, considerable work is still required to develop low-mortality turbines for intermediate head values.

VLH (very low head) «fish friendly» turbine.

Finally, the R&D programme studied a number of other systems designed to block access of the fish to the water intakes. An infrasonic repulsion device developed by Profish Technologies was tested for two years, using a radio-monitoring system for 150 eels equipped with emitters, on two sites on the Gave de Pau river with very different layouts. The system failed the test (F. Bau, Irstea) because no significant differences were noted in the behaviour of the eels when equipped with the system.

Isabelle Lebel, Migrateurs Rhône-Méditerranée association

Encourage acceptance of solutions by the people in the field

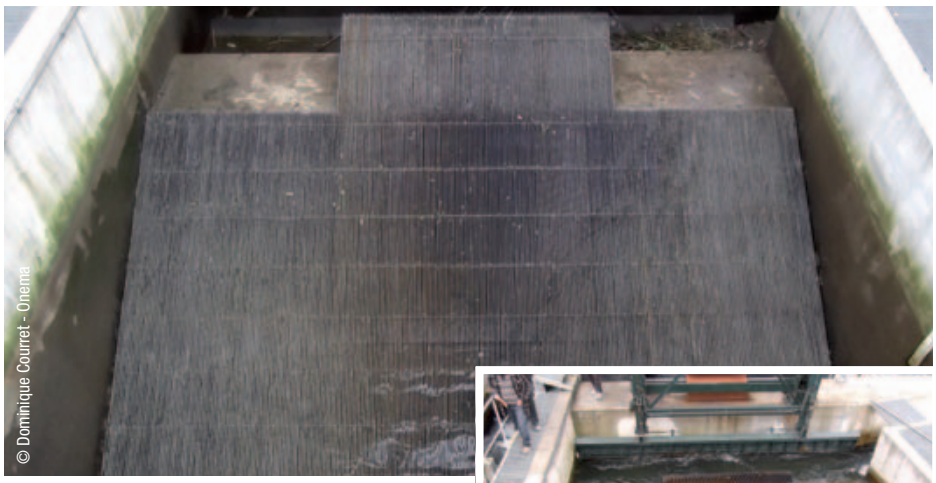
«The work carried out in the R&D programme produced new knowledge on eels and their behaviour during migration. The proposed technical solutions are of the greatest importance for the survival of the species and must now be made available to the people in the field. That will require collaboration between all State services, a major effort in terms of communication and promotion, and work to clarify issues concerning the ownership of installations.»

Given the lack of effective, repulsion techniques, the best solution, if economically feasible, remains screens positioned upstream of the turbine intakes, with sufficiently small distances between the bars to block access by eels. In 2008, a study established the basic parameters for the design and sizing of screens, based on feedback from experiments carried out in France and abroad (D. Courret and M. Larinier, Onema). Two systems have been developed. In the first, the screen is at a sharp angle to the horizontal and virtually perpendicular to the flow of water. The angle guides the fish to one or more bypasses located at the top (see photo opposite). In the second, the screen is vertical and slanted with respect to the flow of water, thus guiding the fish toward a bypass on one side. Following the initial analysis, a complete study (S. Raynal and L. Châtellier, Institut P') in an experimental channel was launched to develop load-loss equations for these specific systems, taking into account their geometrical parameters. An additional study is now underway, in the framework of a partnership between Onema and the hydroelectric companies (SHEM, CNR, EDF, FHE) and should be terminated by the first half of 2013. The results of all these studies will enable the State services and the industrial companies to better understand the technical modifications required in installations to help in saving the eel.

Patrick Lacombe, Departmental territorial and maritime agency of the Landes department

Help the private owners of installations

«Many installations no longer have an owner or are the property of elderly people who, in some cases, do not have the necessary funds. Under these conditions, how can a fishway or its maintenance work be paid for? A specific financial-aid programme would appear indispensable.»



Fish-friendly water intake (drained and full) at Masseys on the Gave d'Oloron river, comprising a screen inclined 24°, with a distance of two centimetres between each bar of the screen and two bypasses at the top that channel 10% of the total turbined water.

Following the termination of the R&D programme, the «installations» part of the eel-management plan must now rapidly shift to operational deployment. It is through concerted implementation by the various participants and on the different management levels, ranging from individual installations to entire river basins, that the technical solutions and tools presented here will contribute to the stock-recovery goals set by the public authorities. A condition for success lies in maintaining consistency between the diagnosis, operational decisions, their implementation and monitoring. Starting with a diagnosis approved by all participants, selection of technical compromises must take into account a cost-effectiveness analysis specific to each installation. The questions concerning the funding for development work now require clear answers, a fact that was emphasised during the discussions between the various participants (water managers, local governments, hydroelectric companies) during the final round table of the symposium.

For more information…

Data sheets on research results and the text of the presentations made during the symposium are available at www.onema.fr/ Programme-de-R-D-Anguilles.

The recap document for the Eels & Installations R&D programme will be published in 2012 at http://www.onema.fr/collection-les-rencontres-syntheses.

Symposium organisers

Philippe Dupont, Deputy director, DAST Onema

Philippe Baran, head of the Onema-Irstea-IMFT Ecohydraulic centre

Dominique Hauw, executive assistant, Ecohydraulic centre

Steering committee for the Eel-Installations R&D programme

ONEMA
MEETINGS

Publisher: Patrick Lavarde
Coordination: Véronique Barre, Research and development department, and Claire Roussel, Information and communication department
Author: Laurent Basilico
Editorial secretary: Béatrice Gentil
Translation: Cabinet Bartsch
Layout design: Eclats Graphiques
Production: Accord Valmy
Printed on paper from sustainably managed forests by Panoply
Onema - 5 Square Félix Nadar - 94300 Vincennes
Document available at:
http://www.onema.fr/ IIMG/EV/cat7a.html