CELEBRATING 40 YEARS OF WATERPROOFING DAMS AND CANALS

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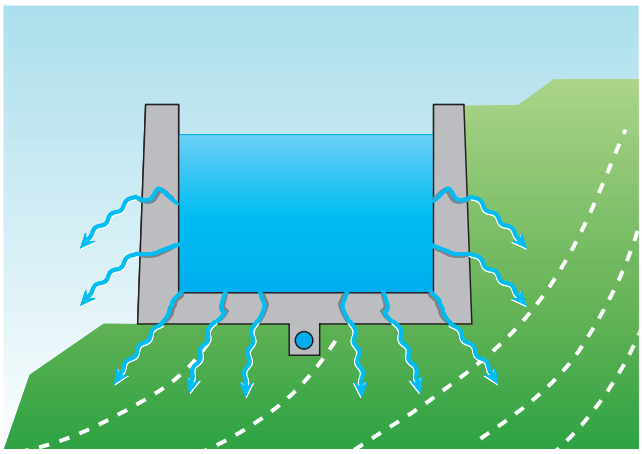
WATERPROOFING SPECIALISTS AND CONTRACTORS WITH GEOMEMBRANES

# CANALS

## WATERPROOFING AND INCREASING WATER FLOW

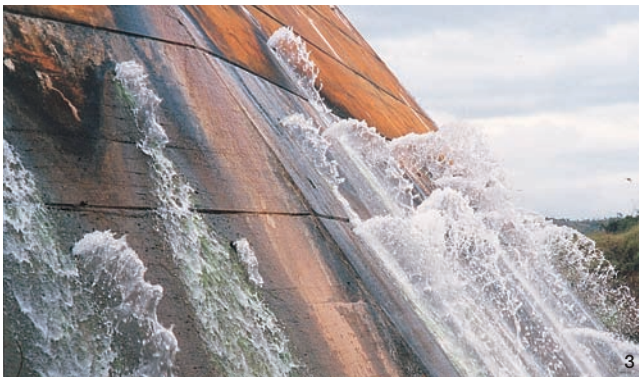
Providing Dry and Underwater Installations

# PROBLEMS



Canals over time face structural deterioration causing water losses and reduction in water flow.
The integrity of the structure is affected by high temperature variances, by the dynamic action of water and transported material, by uplifts, by settling of the surrounding terrain, by the chemical action of aggressive waters. The situation is aggravated by the flow of water within the canal which wears upon the canal liner through friction. Permeability of the structure increases and water is lost through cracks and deteriorated joints. Growth of vegetation concurs to reduce water flow.

1/2 - The aging of the joint sealing material results in water losses and water flow reduction.
3 - The outcome can compromise the structural integrity of the canal and lead to very disturbing situations as pictured.



4/5 - The canal structure and/or lining may collapse due to uplift pressure and freeze/thaw cycles.
6 - Joint sealing detachment due to infiltrations from surrounding soil.
7 - Structural alteration due to settlement.
8/9 - Deterioration of joint sealing material leads to water losses and water flow reductions.

Wasted water and decreased capacity costs the canal owner money through lost revenue by a reduction in hydroelectric power generation or water revenues. Furthermore, the water losses can initiate soil instabilities that lead to sinking or collapsing of the canal banks and/or canal structure requiring expensive rehabilitation construction. The obvious solution is to stop water infiltration into the structure of the canal.

10 - Deterioration of joint sealing material in flumes increases water losses.
11 - Water flow is very abrasive and coupled to poor quality of concrete during construction results in the destruction of the original canal liner.

# PROBLEMS

1 - Cracks in structure provoke water losses and undesired water flows into surrounding soil.
2 - Crack is caused by different expansion properties of existing canal concrete and new concrete used for repair.
3 - Detachement of rigid lining material used for repair.
4 - The powerful action of water flow and undrained water uplift pressures resulted in destruction of this bituminous membrane glued to the concrete after only 6 years of service.
5 - HDPE liners are susceptible to high thermal expansion inducing stress cracking in liner and excessive stresses on liner anchorage system as pictured in this flume lined with a stiff HDPE membrane.

6/7 - The growth of moss and vegetation results in water flow reduction.

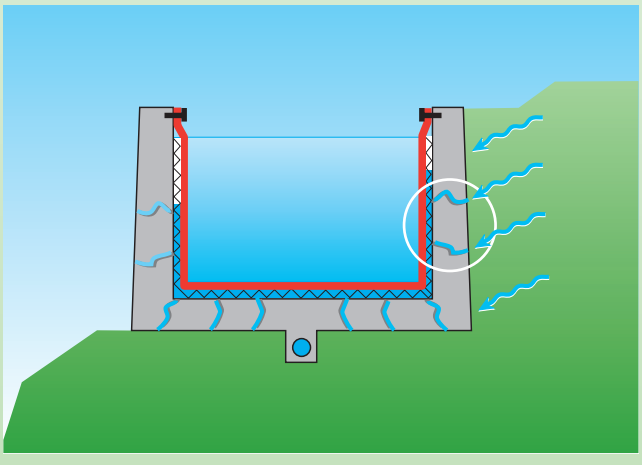
8 - The fissures and permeability inherent with shotcrete used for canal repairs allow the water from the canal to continue to penetrate through the joints between the stones of the original structure.
9 - Excessive roughness due to shotcrete or abrasion of old concrete increases friction losses.

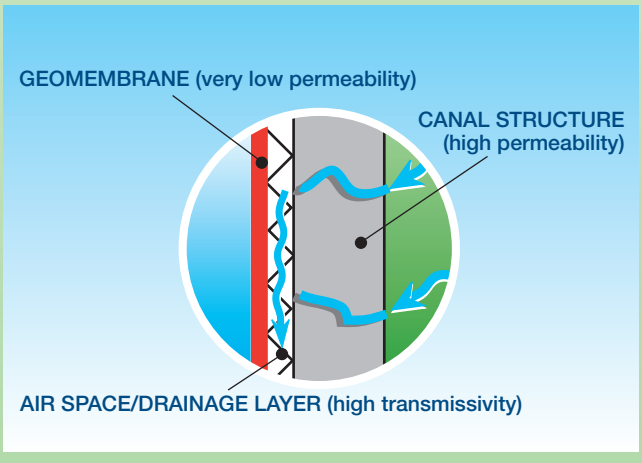
10 - The result of either excessive roughness of the canal lining or growth of vegetation is a reduction in the design flow capacity of the canal.
11 - Excessive roughness from the abrasion of the existing liner reduces the design flow. Overtopping of canal walls releases water into the canal's adjoining soil leading to instability of the canal foundation. The result is a high risk of collapse of the canal structure.

## INSTALLATION OF A WATERPROOFING DRAINED GEOMEMBRANE PROVIDES THE FOLLOWING

### BENEFITS
provided by the CARPI system

- WATERPROOFS THE WHOLE CANAL COURSE, JOINTS AND CRACKS INCLUDED
- STOPS WATER LOSSES
- INCREASES WATER FLOW CONSIDERABLY
- IMPROVES STABILITY OF THE STRUCTURE AND OF SOIL
- PREVENTS CONTAMINATION OF WATER INSIDE THE CANAL
- PROTECTS FROM FURTHER DETERIORATION
- REDUCES FORMATION OF VEGETATION AND ALGAE
- PROTECTS THE ENVIRONMENT
- MINIMIZES MAINTENANCE
- IS VERY LONG LASTING AND COST EFFECTIVE



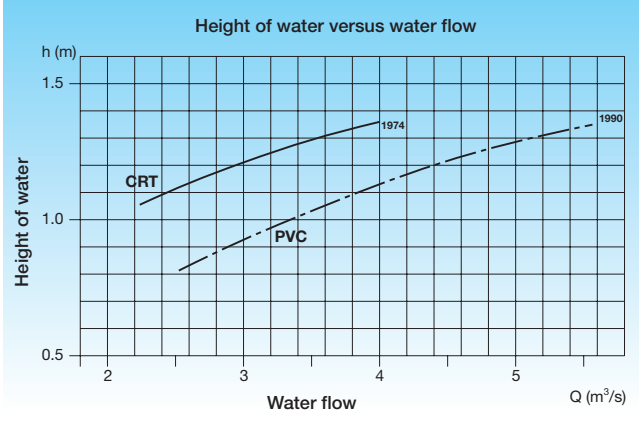



## CASE HISTORY ON INCREASING CANAL WATER FLOW USING A DRAINED GEOMEMBRANE SYSTEM

The existing hydropower canal has a rectangular cross section (width 2.5 m, height 1.5 m) and was lined with concrete (CRT). After only 6 years in service the canal water flow was measured and had fallen to 4.0 $m^3$/sec with 1.35 m water depth (Table A, CRT curve). The owner decided to regain the original design flow and increase the total canal flow by installing a CARPI PVC geomembrane system. The CARPI PVC geomembrane system included mechanical fastening for geomembrane attachment allowing the PVC geomembrane to be left exposed on the inner section of the canal, dramatically increasing total canal flow. The canal flow was again measured after the CARPI PVC geomembrane system had been in service for 7 years. The new measurement indicated a flow, with a reduced hydraulic head of 1.30 m (Table A, PVC curve), representing a more than 40% increase in canal flow capacity.

In other cases, increases of up to 90% in canal water flow have been documented with a value of "n", the coefficient to be used in the Manning (Gauckler-Strickler) formula, of less than 0.0115. This value is a global figure for the entire canal and is not related solely to the geomembrane material.

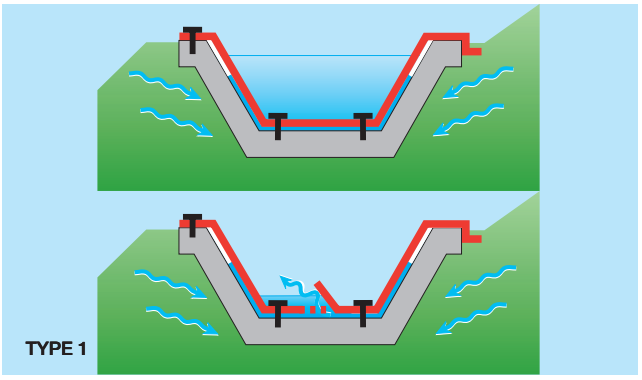
**TABLE A - Increased water flow**

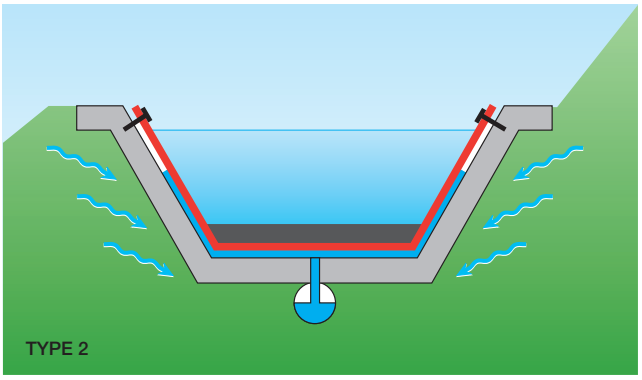


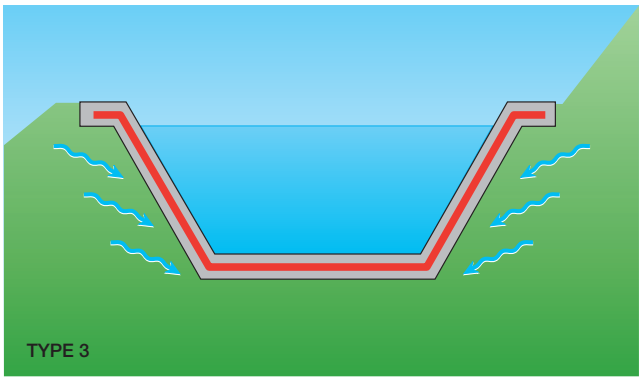

The use of a manufactured PVC product has several advantages:
- watertightness is several orders of magnitude more impervious than in traditional materials
- material quality is constant and can be laboratory controlled and verified prior to installation
- material has lower frictional losses, enabling the canal to handle significantly higher water flows (average documented increase between 30 and 90%)
- proven long life with installations dating back more than 20 years
- geomembrane systems require lightweight materials for installation which leads to cost effective solutions cheaper than traditional concrete linings
- geomembrane systems require much shorter installation times, therefore reducing loss of operation
- inclusion of a drainage layer behind the membrane insures that water entering the structure from outside the canal is captured and drained away preventing structure deterioration or contamination of water from other sources

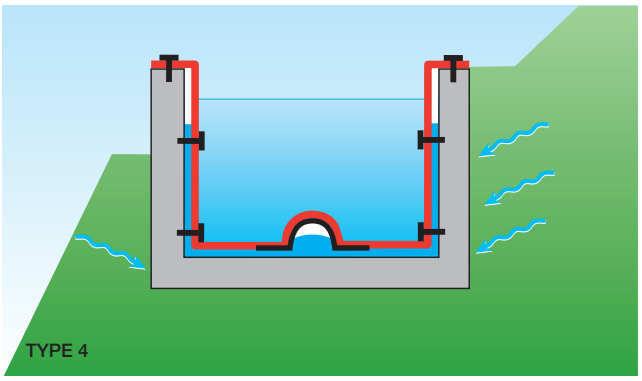
**TABLE B - General criteria for selection of a geomembrane system**

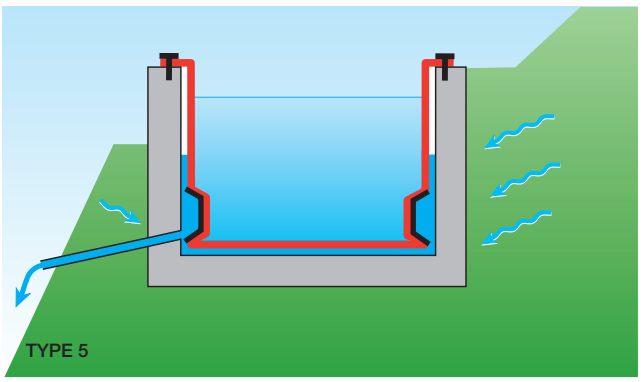
| | CONDITIONS | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **SOLUTIONS** | **CROSS SECTION** | **WATER VELOCITY** | **RESISTANCE TO UPLIFT** | **SUBGRADE** | **DRAINAGE REQUIRED** | **PROTECTION REQUIRED** | **WATER FLOW INCREASE** | **COST** |
| **TYPE 1** | SMALL | < 1 m/sec | LOW | SMOOTH | YES | NO | MEDIUM | LOW |
| **TYPE 2** | ANY | < 2 m/sec | LOW | SMOOTH/DAMAGED | YES | YES | LOW/MEDIUM | LOW/MEDIUM |
| **TYPE 3** | ANY | < 3 m/sec | MEDIUM/HIGH | DAMAGED | NO | YES | NONE | MEDIUM/HIGH |
| **TYPE 4** | ANY | < 4 m/sec | MEDIUM | DAMAGED | YES | NO | HIGH | MEDIUM |
| **TYPE 5** | ANY | < 5 m/sec | MEDIUM | DAMAGED | YES | YES | VERY HIGH | HIGH |
| **TYPE 6** | ANY | <10 m/sec | HIGH | HIGHLY DAMAGED | YES | NO | VERY HIGH | HIGH |

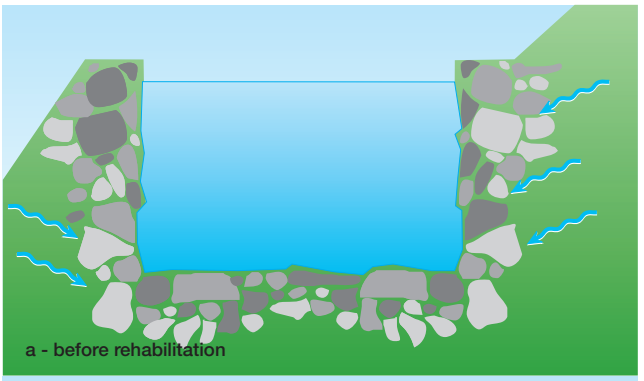


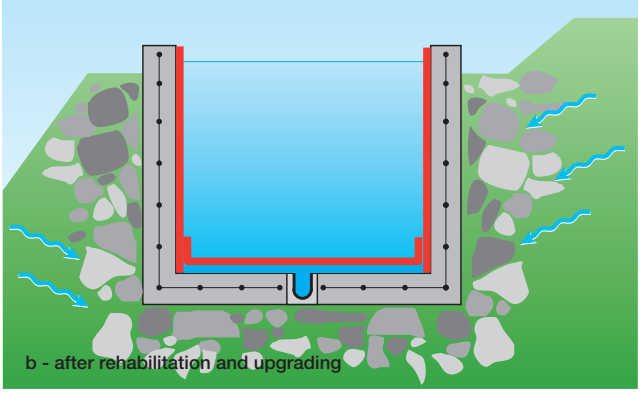



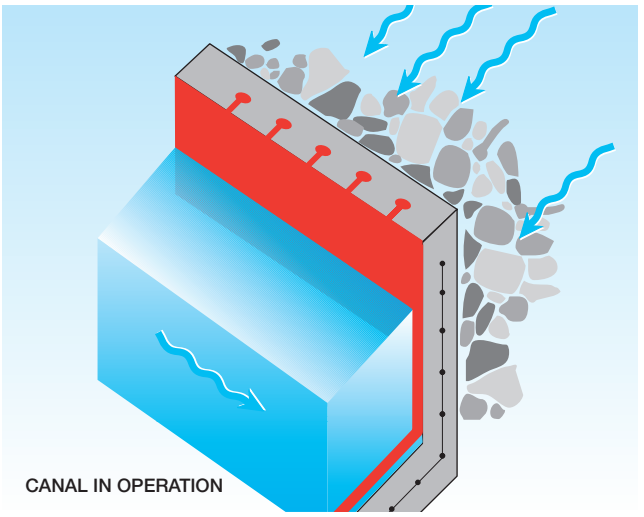



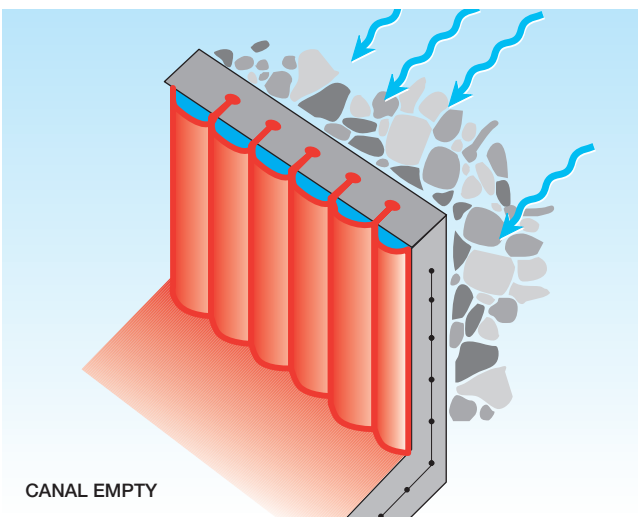




TYPE 6 - SIBELON CL - See also Construction, photographs 13-14

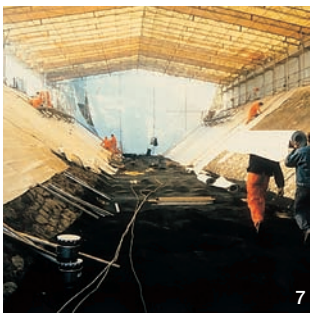



Elasticity and embedded ribs of CL geomembrane allow discharge of uplift pressure when canal is empty.

# CONSTRUCTION

1 - Installation of the waterproofing PVC geomembrane over the drainage layer.
2 - The CARPI waterproofing geomembrane systems can also be installed underwater eliminating the need to dewater the facility.
3 - Recommended surface preparation: hydroblasting to eliminate loose surface material. The CARPI geomembrane system reduces installation costs by dramatically reducing surface preparation costs.
4 - Construction of drainage collection system: installation of a geonet on the inner walls and bottom, construction of longitudinal drainage pipe embedded in the invert.
5 - Geomembrane sheet installed longitudinally over the subgrade. Frequently no synthetic drainage layer is required in small cross section canals.
6 - Geomembrane sheet installed over the synthetic drainage layer (i.e.: geonet).



7 - Mobile cover structures allow construction in tough climatic conditions (rain, frost, snow...).
8 - Seaming of adjacent sheets of geomembrane.
9 - Geomembrane sheets installed longitudinally over bottom, transversally over slopes.
10 - Pouring concrete on bottom to allow traffic of heavy equipment for debris removal.
11 - When the watertight geomembrane is not installed on the entire cross section of the canal, the submerged perimeter seal must be properly connected to the existing structure. Construction of a new perimeter concrete beam and contact grouting may provide an efficient anchoring structure for the low longitudinal perimeter seal.
12 - Watertight seal is constructed at all peripheral surfaces.

## CASE HISTORY OF HEAVY REHABILITATION (see TYPE 6)

Badly deteriorated canals require pouring of new reinforced concrete against the existing structure. A CARPI CL liner is embedded into the new concrete walls. The low coefficient of friction of the CARPI liner allows the water flow capacity of the canal to increase despite the reduction in the cross section due to the thickness of new concrete and liner.

13 - The CL geomembrane sheets are placed over steel reinforcement mesh, against formwork, before concrete pouring.
14 - Formworking proceeds as new walls embedding CL geomembrane are constructed.

# OPERATION

**The CARPI system with exposed geomembrane has proven durability record measured in decades while providing watertightness and increased canal flow.**

1 - Resistance to impact: rocks that fall into the canal roll over the geomembrane and are transported by the flow. The geomembrane has been tested to verify its ability to withstand severe impacts.

2 - Low hydraulic roughness: increase in water flow due to installation of the geomembrane and reduction in liner uplift pressures due to the drainage system behind the geomembrane.

3 - High resistance to ultraviolet rays: the CARPI geomembrane is custom formulated to withstand ultraviolet radiations. Laboratory tests performed on samples from existing installations, that have been in service more than 20 years, show no significative change in geomembrane characteristics, signifiying the geomembrane waterproofing life will easily exceed 50 years.

4 - High resistance to mechanical stresses. CARPI does not recommend driving cars on geomembranes, but it is done and it works!


1


2


3


4

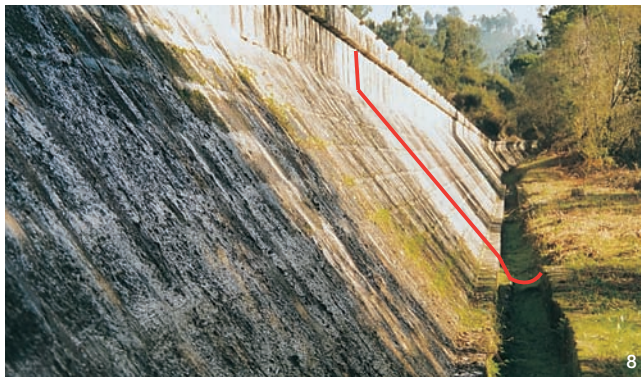
5 - After installing the CARPI geomembrane system this canal had a documented increase in water flow capacity (from 10 to 19 $m^3$/sec).

6 - High resistance to water velocity: CARPI's patented mechanical anchorage system for the geomembrane allows it to withstand water velocities in some cases up to 10 meter/sec.


5


6


7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7 - High resistance to puncturing and burst: CARPI geomembrane system has been installed on very aggressive substrates without any deterioration in performance. Extensive laboratory tests have been conducted on sample substrates to verify geomembrane system robustness.

8 - Complete watertightness: the red line in the picture marks the end of the canal waterproofed with the CARPI geomembrane system (in further distance), showing the desaturation effect of a drained geomembrane liner.


9


10

9/10 - High resistance to turbulence and suction depends on appropriate design and thorough quality control during installation (photo 9, immediately after construction, photo 10 after 7 years of service).

11 - Watertightness: the CARPI system provides a cost effective long lasting solution to leakage. The photo shows how the CARPI geomembrane system eliminated the leakage shown on page: Problems, photo 3, left.


11

Senhora do Porto - Portugal

Gaggio - Italy

Signayes - Italy

Soulom - France

Pointis - France

Campilhas - Portugal

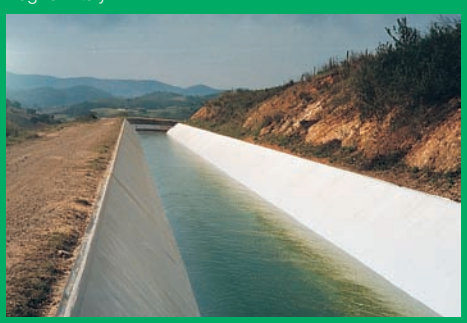
Poschiavino - Italy

Finges - Switzerland

Zogno - Italy

Itutinga - Brazil

Mittlere Isar - Germany



Mira - Portugal

**More than 1,200 CARPI installations performed worldwide with projects already completed in Europe, Africa, Asia, North, Central and South America.**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Underwater installation on Lost Creek dam - USA
Winner of the 1998 West Region Award of Merit from the Association of State Dam Safety Officials (ASDSO)


Project: Age Ltd - London (UK) Executive: GEA Srl - Arona (Italy)