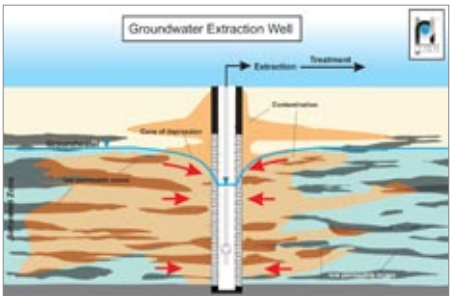
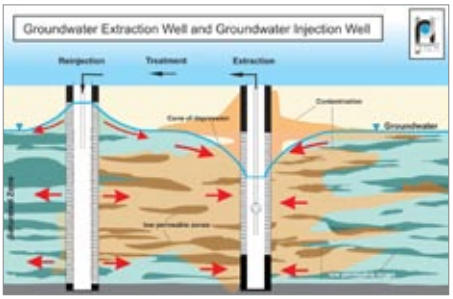
GENERAL PRINCIPLES OF GROUNDWATER CIRCULATION WELL (GCW) TECHNOLOGY

Inducing a circulating flow field using a Groundwater Circulation Well (GCW) as ameans of efficiently remediating contaminated groundwater.

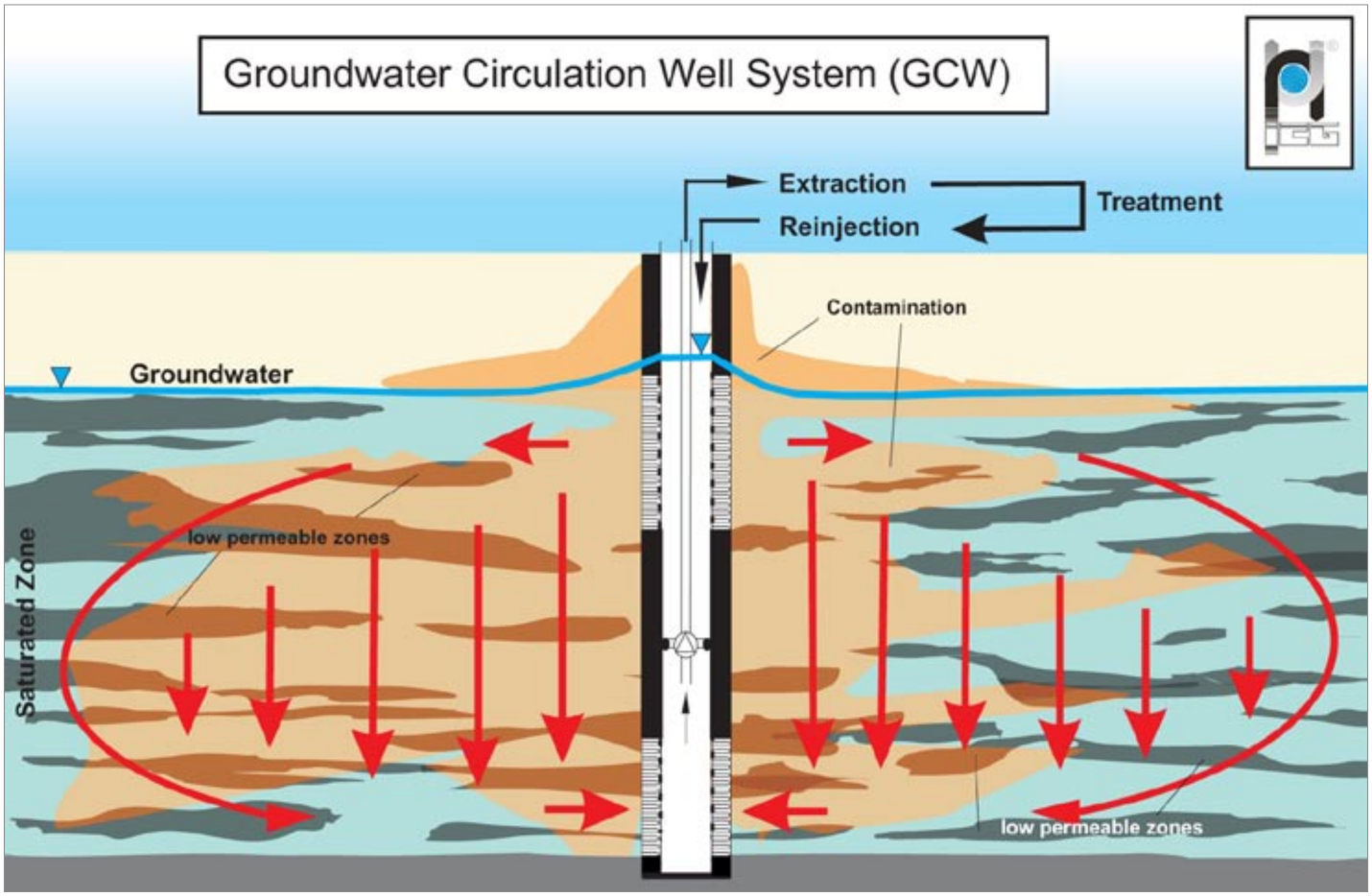
With the conventional „Pump & Treat" method, groundwater is normally extracted from one or several wells, cleaned above ground and disposed off to the either groundwater or surface water. Even when extraction and injection wells are combined, predominantly higher permeable areas are preferentially penetrated and more fine-grained structures are circumflowed. The bulk of contaminants are absorbed to the less permeable materials like fine- grained sands, silty or clayey layers. By diffusion, the contaminants are released out of these reservoirs very slowly. After a short period of time they effect a stagnation of the contamination discharge („Tailing Effect").

Depending on subsoil conditions (geology and hydro-geology) and contaminant type and concentration, remediation of sites can take several decades. Consequently, „Pump & Treat" technique is considered as being suitable and effective only for containment to prevent further spreading of contaminants, but is no longer considered as a remediation method.



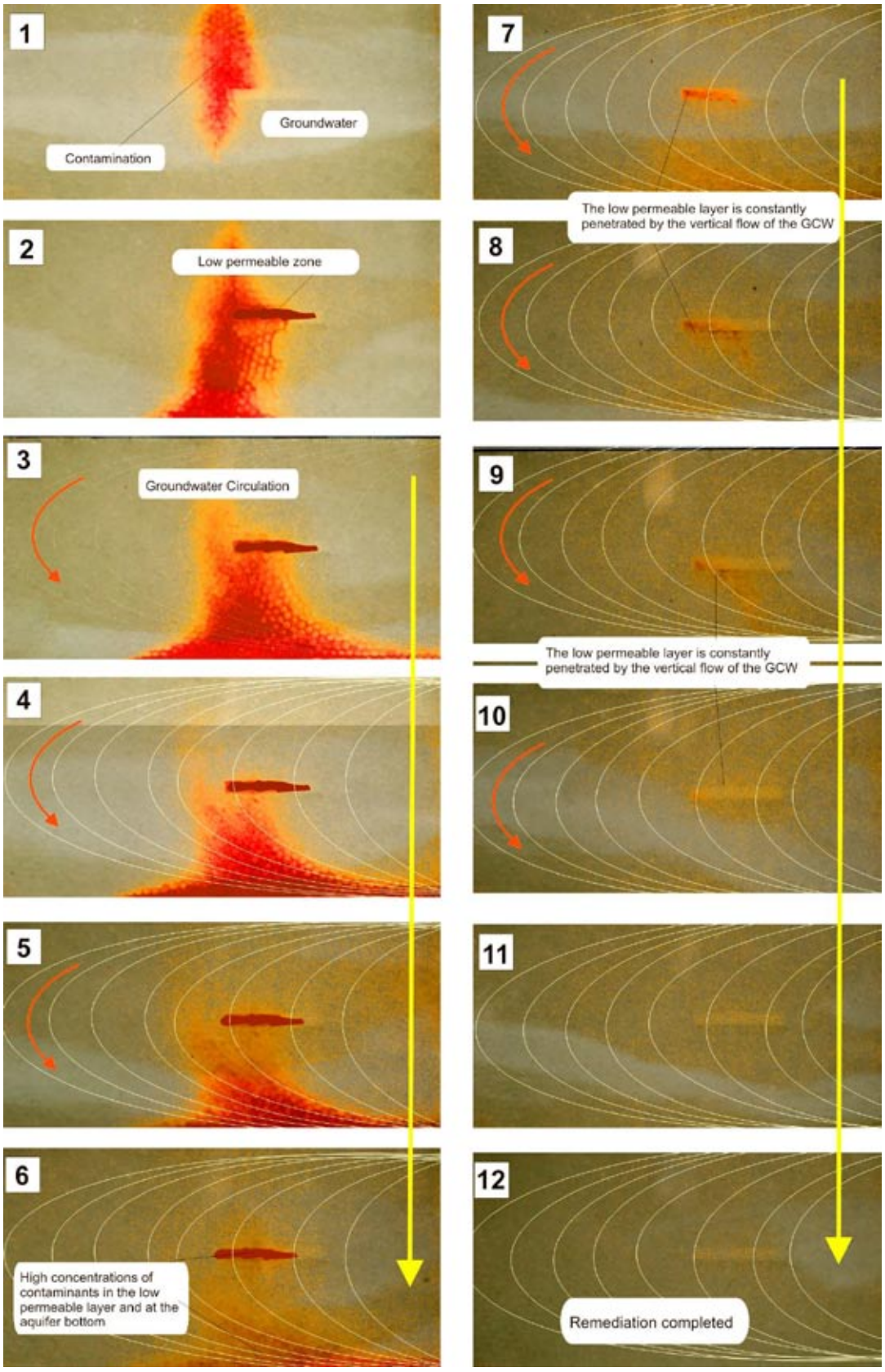


With the „Pump & Treat" method groundwater is radially extracted out of the aquifer. Due to a change in the hydraulic gradient, both contaminated and clean groundwater flows through the contaminated subsoil and is constantly treated above ground with considerable technical effort. GCW systems are designed to create in-situ vertical groundwater circulation cells by drawing groundwater from an aquifer through one screened section of a multi-screened well and discharging it through another screened section. If a circulation flow is generated in the aquifer, the treated groundwater is circulated several times in the aquifer before it flows downstream. This guarantees a considerably more efficient course of remediation compared with the „Pump & Treat" method.



GENERAL PRINCIPLES OF GROUNDWATER CIRCULATION WELL (GCW) TECHNOLOGY

GCW Remediation process in an artificial inhomogeneous aquifer (cut half-symmetrical), (circulation flowlines: yellow)



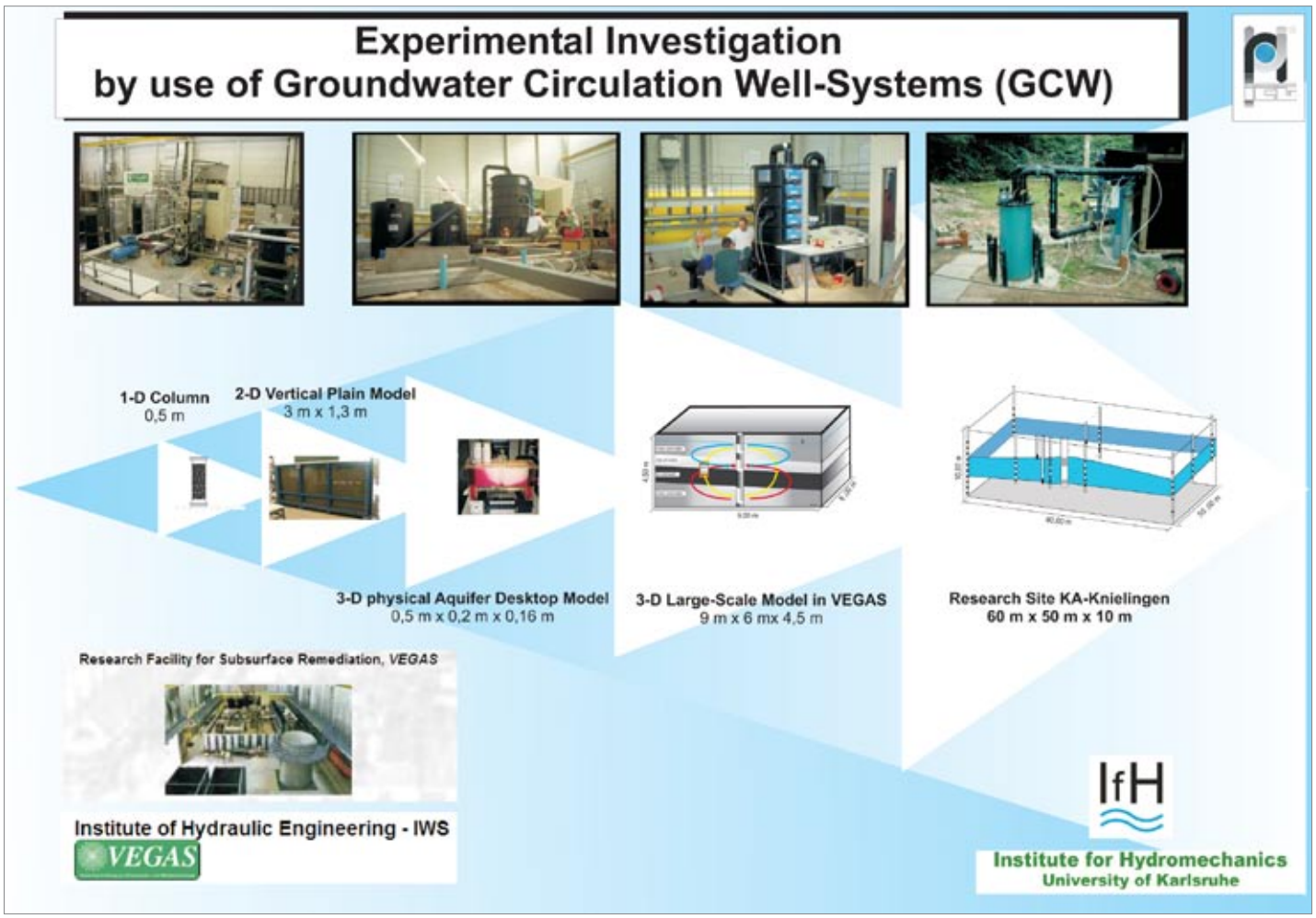
GENERAL PRINCIPLES OF GROUNDWATER CIRCULATION WELL (GCW) TECHNOLOGY

GCW Remediation process in an artificial inhomogeneous Fine-grained, silty or clayey layers and lenticular intercalations are typical for many quaternary sedimentations, where horizontal flow can circumvent at the borders, but since there is a clearly defined vertical hydraulic gradient, a forcing flow through less permeable formation lenses develops. Thus, contaminants can be mobilized effectively and consequently the remediation period can be shortened. Even in low yielding aquifers the employment of GCW can be advantageous. The scientific calculation methods for the hydraulic functioning of GCW-Systems with pump and packer are developed by the Institute for Hydro-Mechanics, University of Karlsruhe, under a research program funded by IEG.

Under university oversight, an objective evaluation of the system was executed within the scope of large-scale model experiments in the research institution VEGAS and at the research site Knielingen by the Universities of Stuttgart and Karlsruhe. Research projects, comprehensive scientific modellings, hydraulic tests and tracer experiments prove the effectiveness of GCW at numerous remediation sites. Practical experience with GCW systems has been present for more than 20 years.

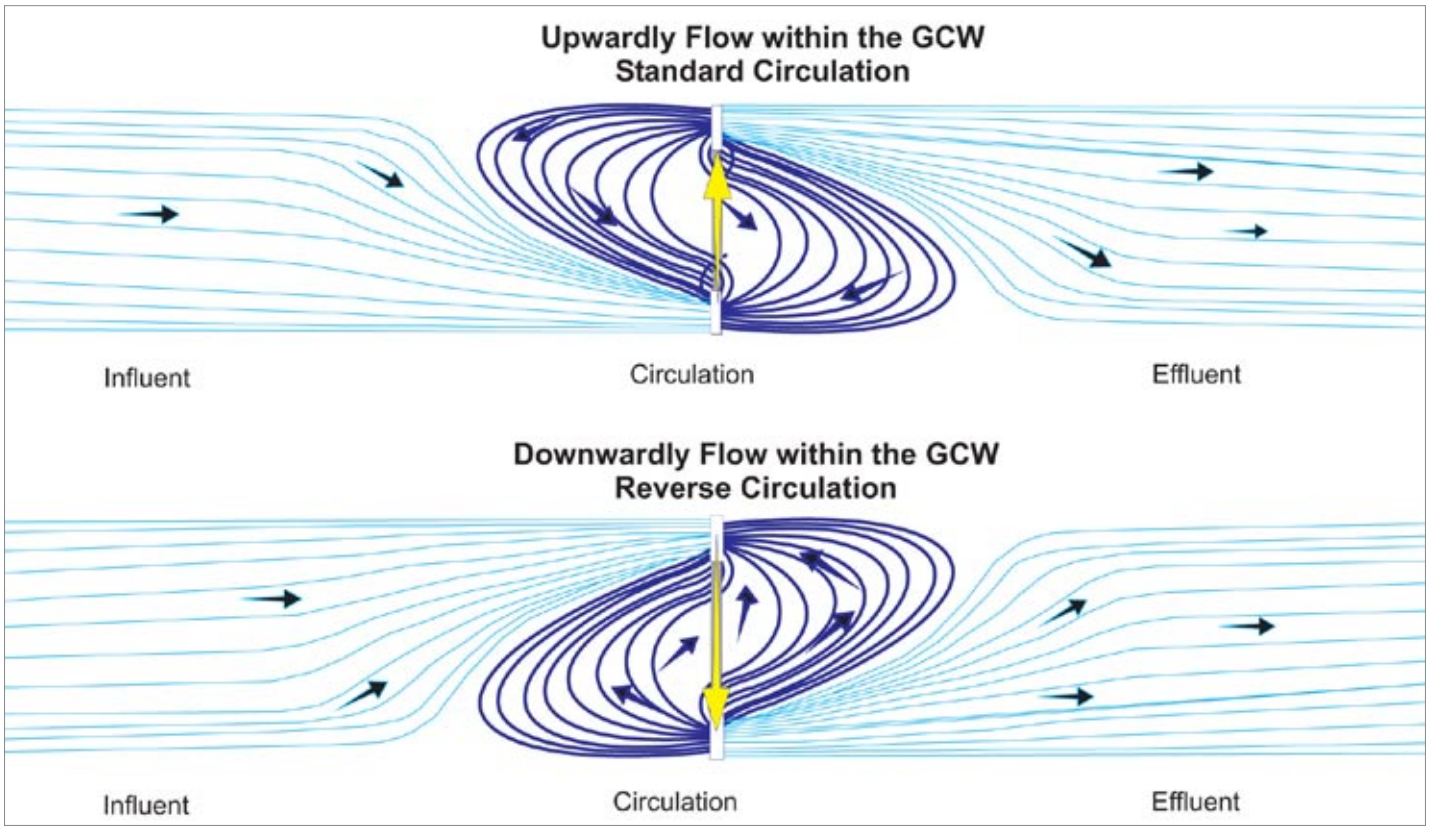
The GCW technology was developed in a way that it can be continuously operated and requires little maintenance only. Infiltration wells, drain pipes into discharge systems or sewer and discharge fees are not necessary.

The investment costs of the systems are within the limits of conventional remediation techniques. Compared with conventional remediation methods, comparatively low operating costs and simultaneous reduction of the remediation period finally allow for considerable cost savings with the employment of circulation techniques. Corresponding with the remediation conception, one or several vertical wells with at least two screen sections are installed in an aquifer. In case of two aquifers, separate GCW-systems are installed. The direction of rotation of the circulation flow can be changed by using a Two-Pump system The circulation flow can be adapted to both the distribution of contaminants and the remediation progress.



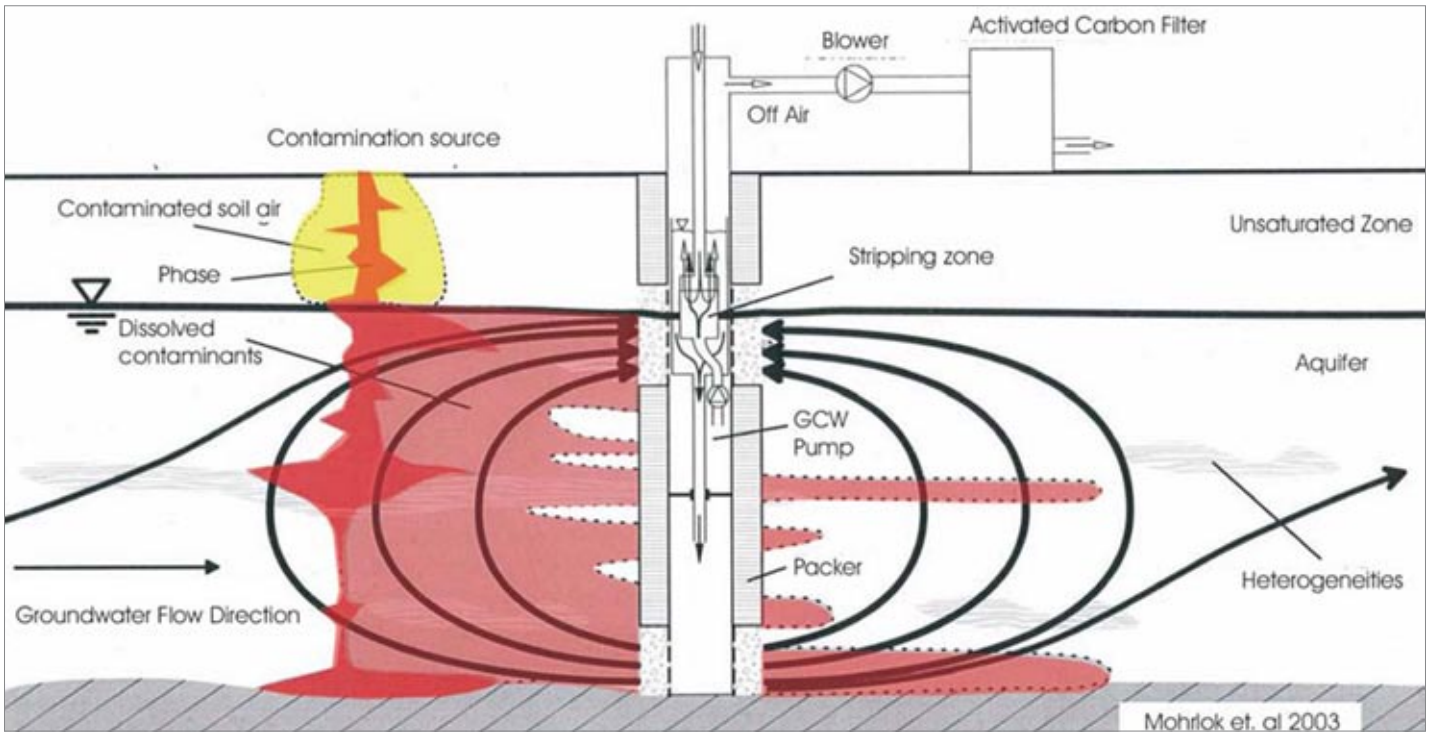
GENERAL PRINCIPLES OF GROUNDWATER CIRCULATION WELL (GCW) TECHNOLOGY

Groundwater circulation commonly occurs from the top of the formation to the bottom (herein termed "standard flow"). Under standard flow conditions, groundwater is pumped upward inside the remediation well as it enters a lower screen section and exits an upper screen section. Groundwater flow upward through the GCW can be achieved via an air-lift effect, or it can be induced via a submersible, in-well groundwater circulation pump. Using a pump offers the advantage that the water/air ratio can be controlled and the stripping performance can thus be adjusted and an internal well short circuit can be avoided at the same time. The circulation cell flow path thus encompasses groundwater flowing from the upper part of the treatment zone into the lower part. Also areas with low penetrability are intensively penetrated horizontally and vertically. In a reverse circulation mode, the flow of groundwater within the GCW well is downward via the aid of an in-well groundwater pump (i.e., water flows from the bottom of the aquifer formation in a toroidal upward pattern). In the reverse circulation mode, water in the lower half of the aquifer moves away from the well, while water in the upper half of the aquifer moves toward the well. In both the standard and reverse flow modes of operation, groundwater is circulated around the central GCW, but none is removed from the aquifer. Induced differences in potentiometric head establish and maintain the 3-dimensional circulation cell in an ellipsoidal area around the circulation well. The majority of the groundwater captured by the circulation cell circulates a number of times through the GCW before being released down-gradient. As such, water serves as the in-situ carrier bringing constituents of interest (COI) from throughout the capture zone to the GCW system where it is treated and then discharged back into the formation. The vertical and horizontal circulation flow patterns force water to move through the entire aquifer portion within the circulation cell thus improving COI mobilization by forcing flow through less permeable formation lenses. With natural groundwater flow, the total amount of water circulating around a GCW will consist of up-gradient groundwater being captured.

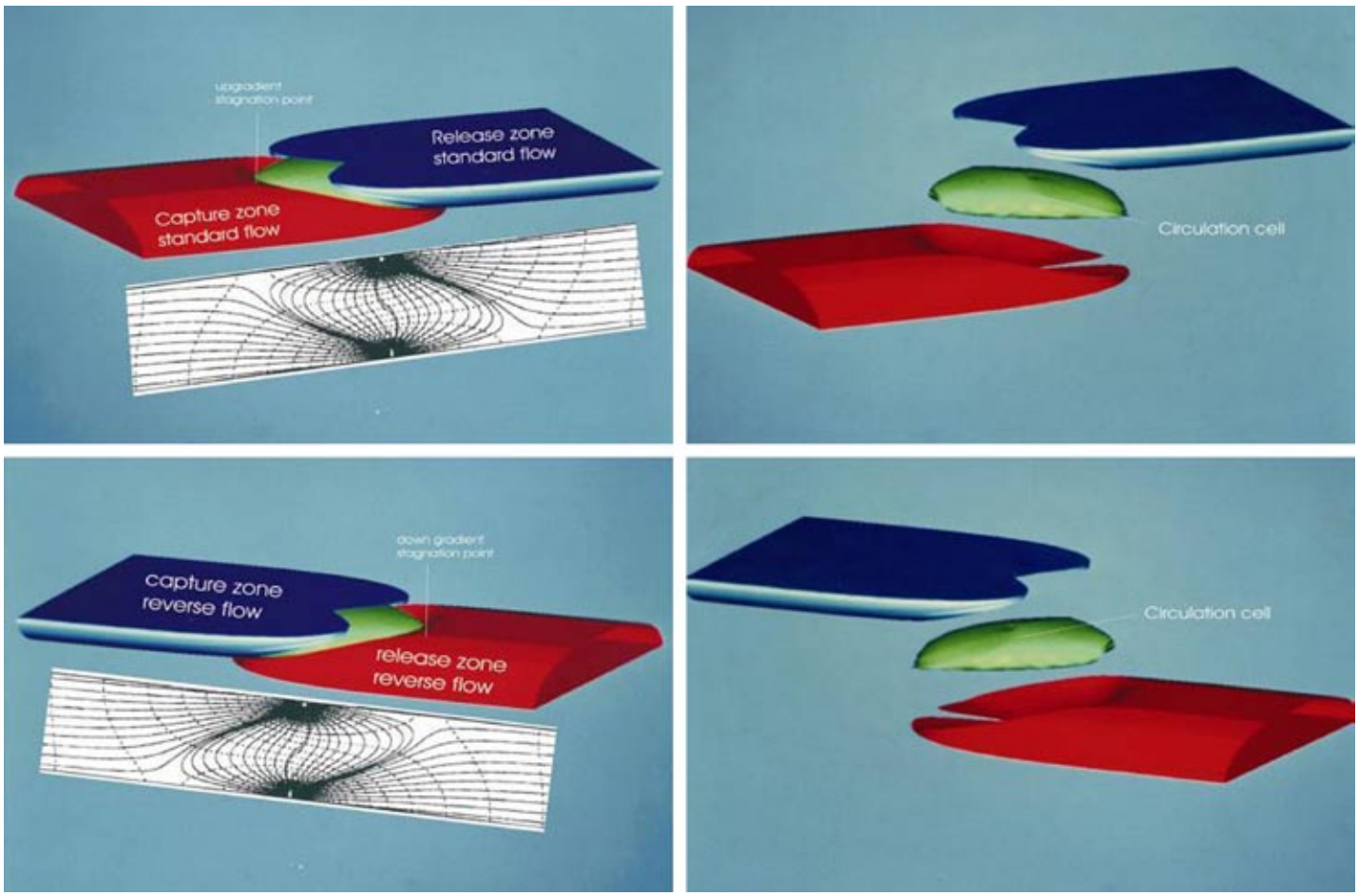


As such, water serves as the in-situ carrier bringing constituents of interest (COI) from throughout the capture zone to the GCW system where it is treated and then discharged back into the formation. The vertical and horizontal circulation flow patterns force water to move through the entire aquifer portion within the circulation cell thus improving COI mobilization by forcing flow through less permeable formation lenses. With natural groundwater flow, the total amount of water circulating around a GCW will consist of up-gradient groundwater being captured, groundwater being recirculated and groundwater of down-gradient release zone following treatment. The flow dynamics and the dimensions of the up-gradient areas („Capture Zone"), of the circulation cell (''Circulation Cell") as well as of the down-gradient area („Release Zone") are used for remediation planning. These dimensions and the circulation time depending on the distance from the GCW can be calculated for a specific site and used as a design tool based on numerical simulations of the groundwater hydraulics.

GENERAL PRINCIPLES OF GROUNDWATER CIRCULATION WELL (GCW) TECHNOLOGY



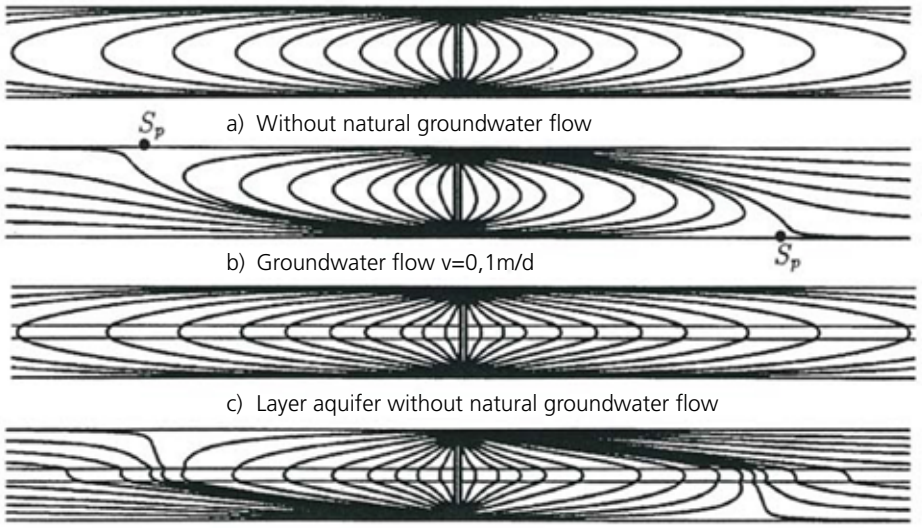
General flow model of a GCW („Reverse Circulation") modified after Mohrlok et al 2003



Capture Zone, Circulation Cell and Release Zone of a Groundwater Circulation Well

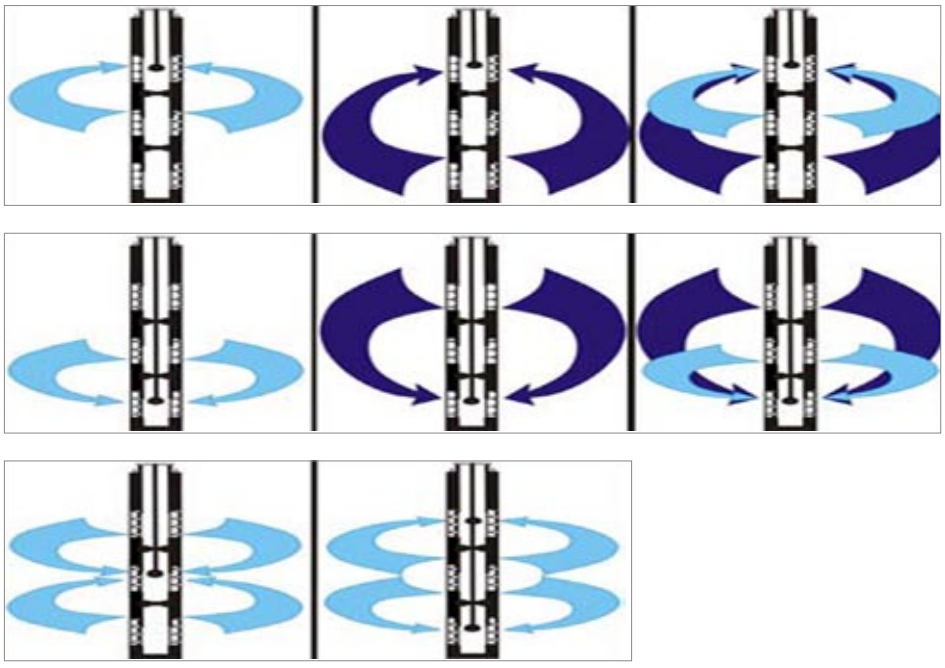
GENERAL PRINCIPLES OF GROUNDWATER CIRCULATION WELL (GCW) TECHNOLOGY

An important precondition for reaching the determined official cleanup concentrations in the aquifer is sufficient penetration of the higher contaminated fine-grained zones, like sandy, silty or clayey layers and lenticular intercalations. For a reliable prognosis of the remediation periods with the Groundwater Circulation System, apart from a precise exploration of the geological conditions, the spatial extension of the contamination area, and an approximate evaluation of the mass of contaminants is required. A decrease of up to 90 % of the original concentration of contaminants in the groundwater is reached by means of several complete circulation passages. Reaching official cleanup concentrations in the µg/l range can take several years.



Path-lines in a Vertical Cross Section through a GCW in an aquifer (HERRLING & STAMM 1992)

DIFFERENT CIRCULATION MODES



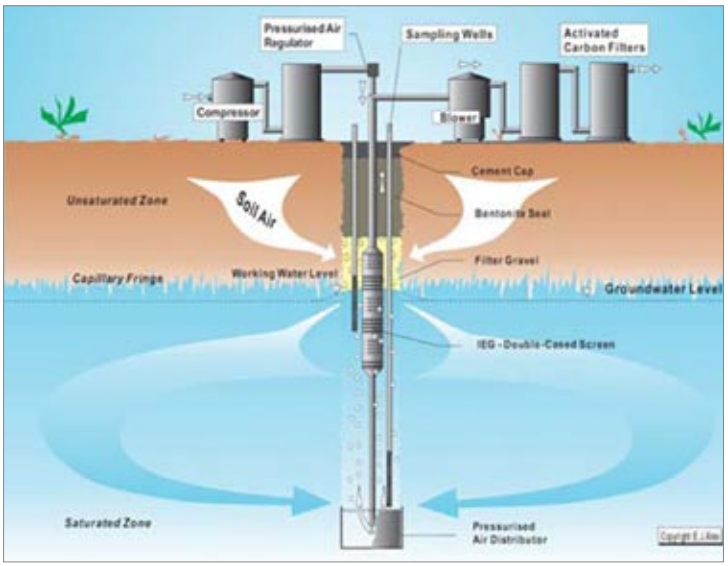
The achievable sphere of influence of a GCW-System depends on the distance of the two active screen sections, the anisotropy of the aquifer, the groundwater flow velocity and the selected pumping rate. The bigger the circulation cell is, the longer a water molecule needs to pass through the cell. With huge aquifers it turns out to be advantageous to arrange several circulation cells (multiple circuits, „stacked circulation") on top of each other. Thus, smaller circulation cells with shorter flow periods are formed.

The application of such multiple-screened GCWs can also be advantageous if the contamination is restricted to certain aquifer sections or if the hydro-chemical characteristics of the groundwater change with the depth of the aquifer, thus requiring dedicated units vertically and horizontally.

GENERAL PRINCIPLES OF GROUNDWATER CIRCULATION WELL (GCW) TECHNOLOGY

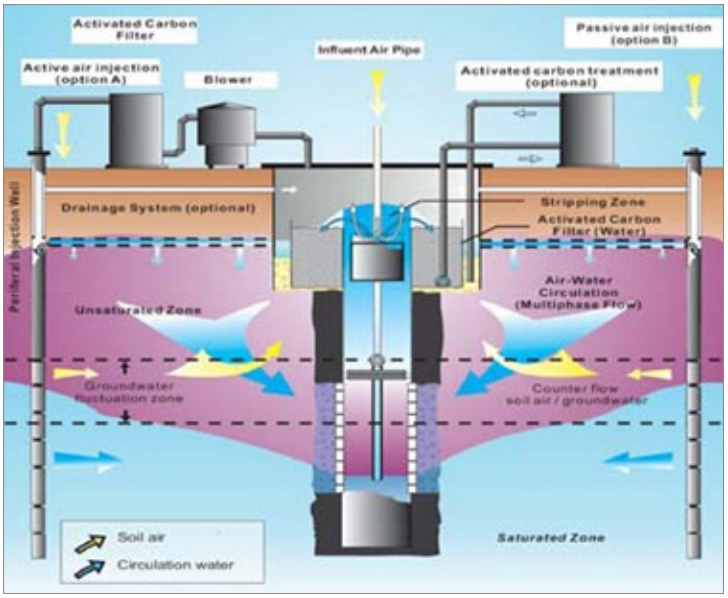
Coaxial Groundwater Circulation (CGC)

Coaxial Groundwater Circulation is a combined technique of soil air extraction and in-situ sparging. With this method, saturated and non-saturated zones are remediated simultaneously. Clean air is injected into a pressurised air distributor at the bottom of the well. The air bubbles rise within the well, causing groundwater to flow upward between the lower and upper annular space of the well. In the capillary fringe area which is straddled by a double cased screen, air is extracted. Thus, groundwater is lifted from the bottom to the top of the well. The groundwater is stripped under low negative pressure. Stripped groundwater flows back into the aquifer and circulates to the bottom of the well.



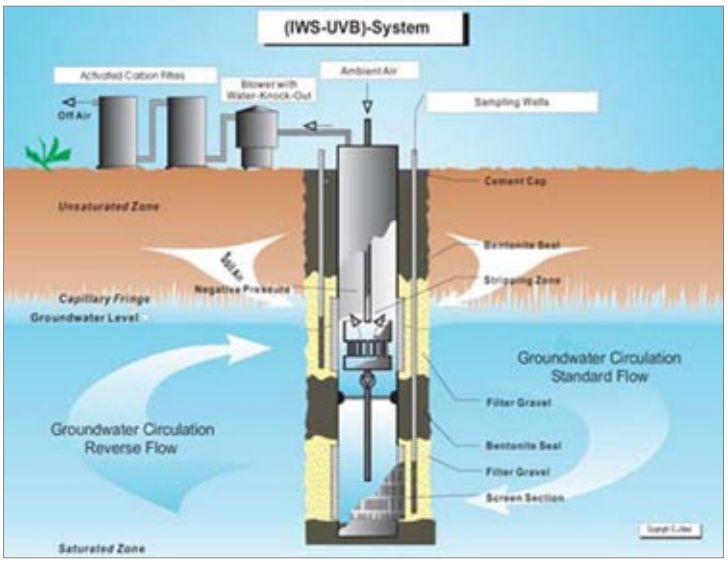
Soil Circular Flushing Well (SZB)

Non-volatile contaminants in the unsaturated zone and in the groundwater fluctuation area can be removed by means of the soil flushing technique. Cleaned and possibly oxygen-enriched groundwater re-accesses the subsoil via drain pipes or vertical screen sections after passing a cleaning system (e.g. bio-reactor etc.). The oxygen saturation as a consequence of the stripping process supports microbiological decomposition in the subsoil. In case of high natural ground water fluctuations, the mostly high-contaminated sector can be included in the remediation, combined with a GCW or a soil air extraction installation.



Soil air Extraction in the unsaturated zone and the capillary zone

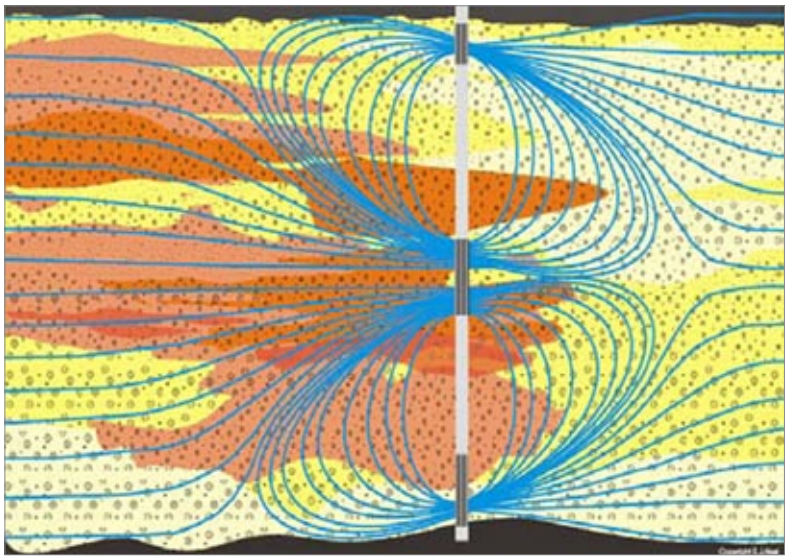
An In-Well Stripping (IWS) UVB system provides apart from In-Well Stripping (IWS) additional extraction of soil air from the unsaturated zone. This leads to an intensive treatment of the mostly high-contaminated capillary fringe. In case of high-contaminated soil air, recontamination of stripped groundwater can be avoided by means of special well constructions. Contaminated groundwater will be stripped under negative pressure for removing the contaminants very effectively. Water/air ratio can be regulated to yield a high stripping efficiency (MTBE etc.)



GENERAL PRINCIPLES OF GROUNDWATER CIRCULATION WELL (GCW) TECHNOLOGY

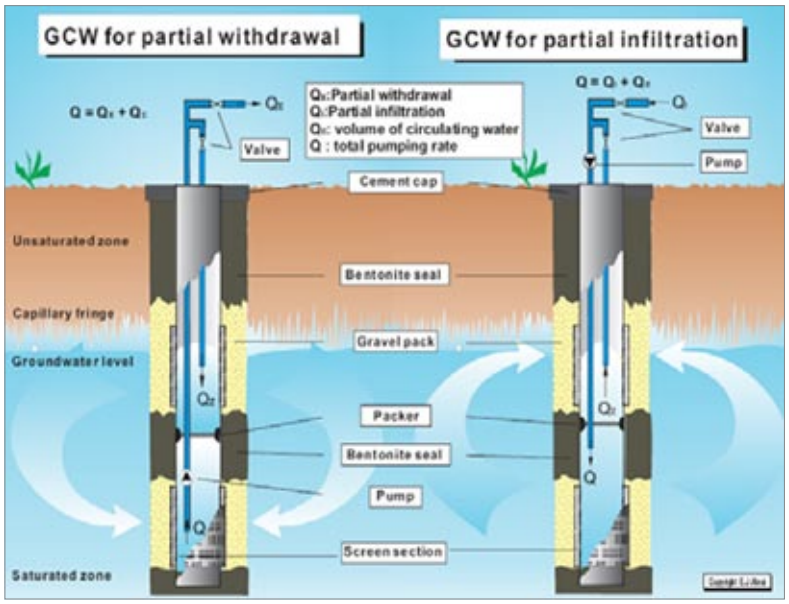
Effective hydraulic flushing by means of several vertically stacked Circulation Cells

Groundwater circulation wells generate a rotation-symmetric circulation flow around a vertical well axis. In the circulation, such areas with low permeabilities are also intensively rinsed-through in vertical direction. Arranging several screen sections in one well allows for variable addressing of single depth horizons. By means of reversion of flow directions and varying pump rates, effective penetration of the subsoil can be achieved.



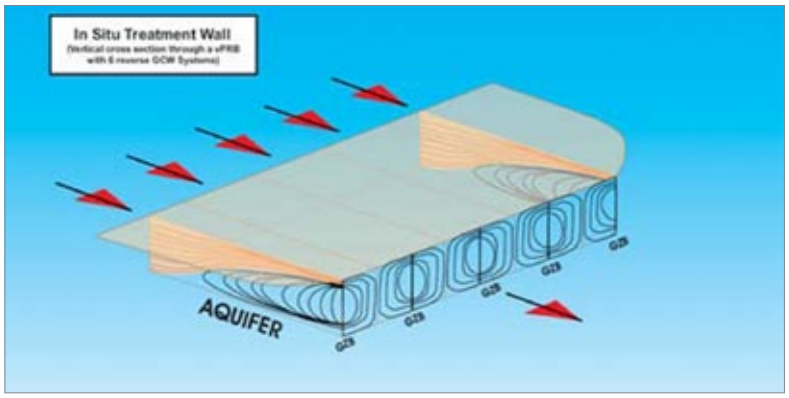
GCW for partial withdrawal respectively infiltration

A GCW can also be operated in a way that a certain quantity of water passing through the well shaft is pumped-off or infiltrated into it. Extracting exactly the same amount of water as the upstream into the well, the groundwater downstream from the well is blocked. Thus, at a remediation site, a complete hydraulic downstream protection of a plume of contaminants with simultaneous exclusive extraction of the injection groundwater can be realized. In addition, there is the possibility to extract water without changing the groundwater level in the well if a certain ratio is maintained.



GCW Well Fields for the treatment of large plumes or large-surface contamination areas

If the width of a plume is larger than the capture zone of a single GCW, several GCWs are arranged in one line perpendicular to natural groundwater flow. By means of rows of GCW wells arranged in series or offset set, aquifers can be intensively remediated also in case of large-surface contaminations. By changing the distance between the GCWs or well series, interaction between the GCWs, with predominantly horizontal flow directions, can also be achieved.



GENERAL PRINCIPLES OF GROUNDWATER CIRCULATION WELL (GCW) TECHNOLOGY

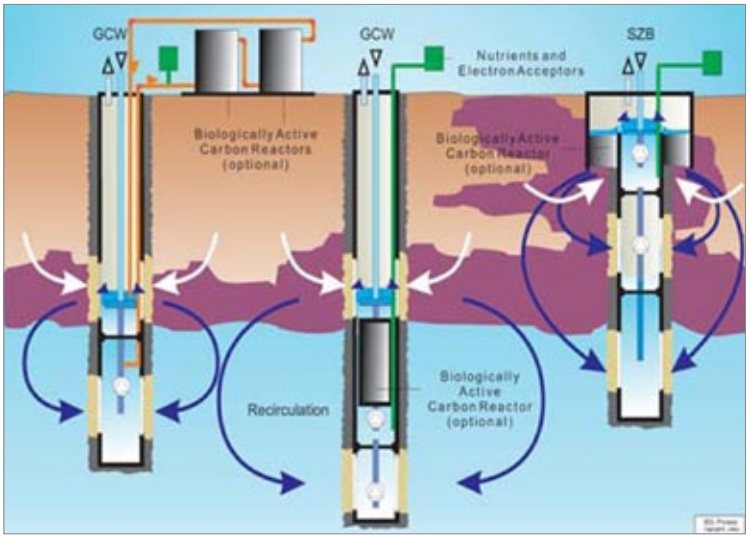
Groundwater treatment

All kinds of purification techniques (strippers, activated carbon, biofilters, ion exchangers, membrane technique etc.) can be integrated into the water circuit. The devices for purifying the polluted groundwater can be installed in the well shaft itself, in a below ground vault or in an above ground placed container. If the circulation flow is used to supply gaseous, liquid or colloidal substances to the water-saturated zone, the aquifer itself becomes the reactor.

CVS-System in container with GAC

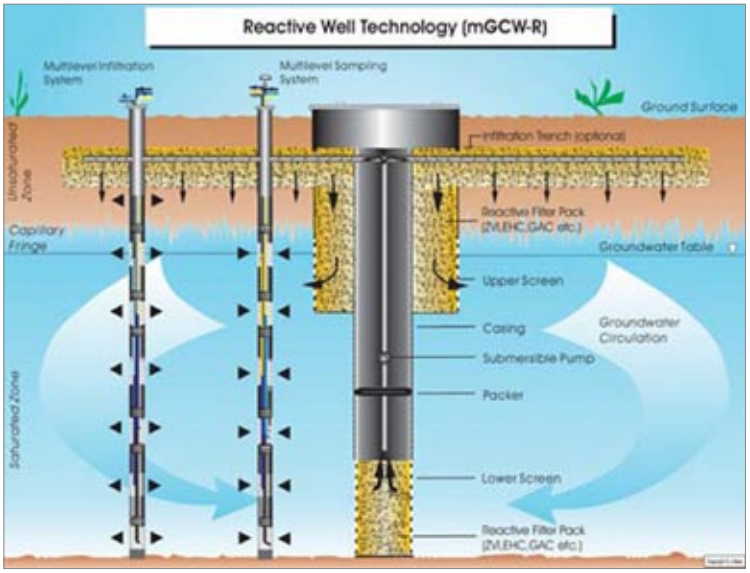
Accelerated biodegradation of contaminants

By means of different techniques oxygen, gas mixtures but also nutrient solutions can be added to the GCW circulation water. Thus, more oxygen-rich and contaminant reduced groundwater circulates through the aquifer and stimulates microbiological degradation respectively creates better bioavailability. Metabolites impeding the growth of auto-chthonic micro organisms or the CO2 produced by the biological decomposition can be transported to the well with the groundwater and can be selectively removed there.



Groundwater Circulation Wells with reactive filling material (GCW-R)

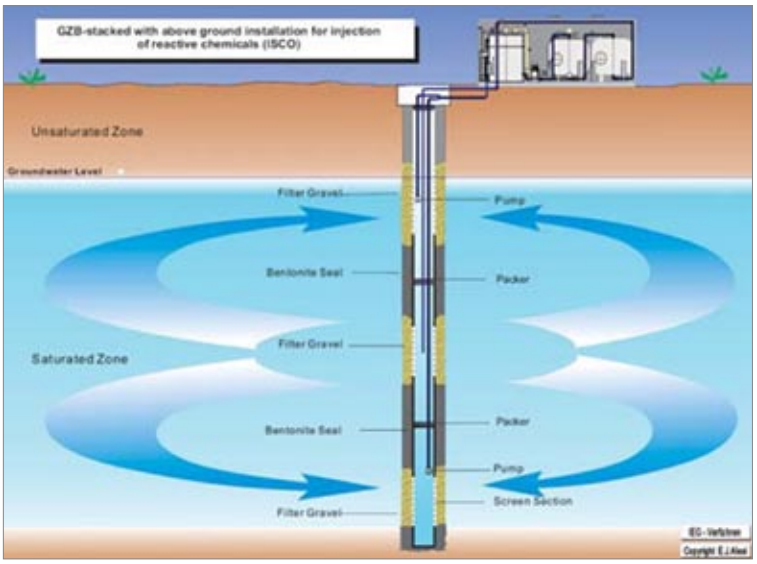
Due to the defined passage through the well system, the catalytic effects of the reactive material can be optimally used. In addition, changing the material is possible at any time. Since the induced groundwater circulation is considerably stronger than the natural groundwater flow, with a one-time passage complete purification does not have to be carried out. Suitable as filling material is e.g. EHC-ZVI which effects, due to the collaboration of physical, chemical and microbiological processes, strongly negative redox potentials resulting in complete degradation of the contaminants (ISCR).



GENERAL PRINCIPLES OF GROUNDWATER CIRCULATION WELL (GCW) TECHNOLOGY

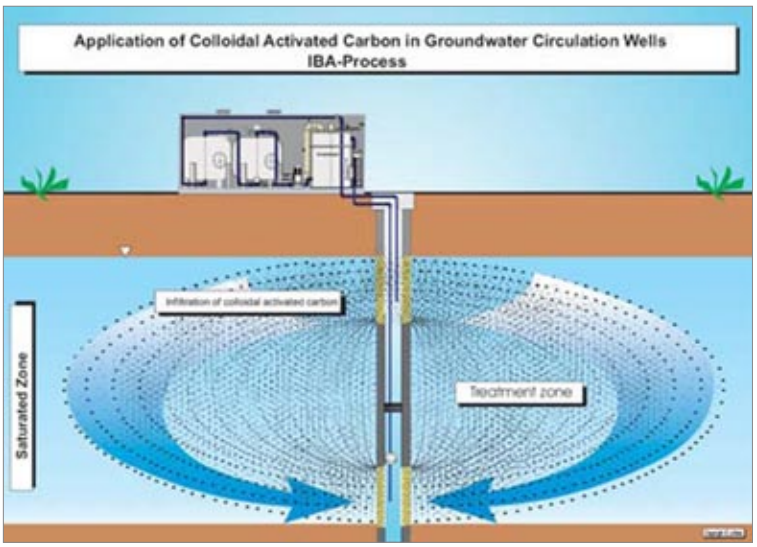
Flushing-in and active dispersing process for chemicals - In situ chemical oxidation (ISCO) or enhanced bioremediation

The chemicals (permanganates, peroxides etc.) required for the execution of ISCO are prepared above ground and fed into the groundwater by injecting it through a GCW. The required quantities should be determined by means of laboratory tests beforehand. To mix in hydrogen peroxide in moderate concentrations will stimulate the aerobic biological degradation. The radial-symmetric circulation fields permit more homogenous and more effective dispersion of chemicals in the subsoil than other hydraulic processing techniques.



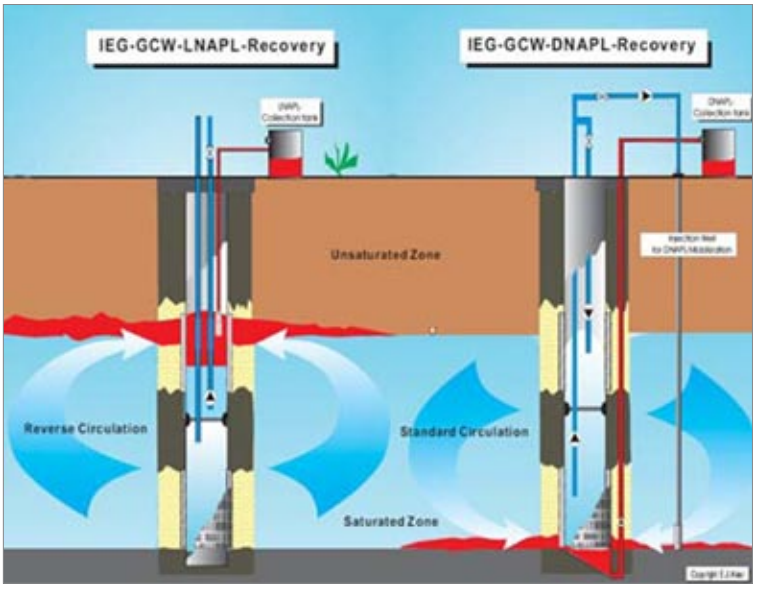
Flushing-in and active dispersing process for substances into the Circulation Flow

The circulation flow can be used to feed liquid agents or substances with the groundwater into the aquifer. Thus, the water represents a carrier medium („shuttle"). Suitable gaseous, liquid, colloid substances or micro-/ nano particles can be added to the circulation water. In this case, the aquifer itself becomes the reactor. In contrast to other hydraulic processing techniques, the radial-symmetric circulation fields permit more homogeneous dispersion of substances in the operation area of the GCW.



Simultaneous Free Product Recovery - Extraction of light and dense non aqueous phase liquids - GCW-LNAPL/DNAPL

With a GCW it is possible to remove non-miscible liquids of lower or higher density than water (LNAPL and DNAPL) from an aquifer. In order to remove light non aqueous liquids floating on the groundwater, the GCW is operated in a reverse mode. In order to remove dense non aqueous phase liquids (DNAPL) that have accumulated on the bottom of the aquifer, the GCW is operated in standard mode. The LNAPL or DNAPL is removed by means of a sensor-controlled, pneumatically-driven submersible pump. Thus it is made sure that just pure phase and no groundwater is extracted.



GENERAL PRINCIPLES OF GROUNDWATER CIRCULATION WELL (GCW) TECHNOLOGY

Potential advantages of GCW technology

- Immediate containment and remediation of dissolved phase plume constituents via in-well stripping.
- Effective in-situ treatment without groundwater removal from the subsurface.
- Only GCW technology that can operate effectively under confined aquifer conditions.
- Only GCW technology that can operate in a reverse-flow and stacked cell mode.
- Uniquely able to regulate the water/air ratio to yield efficient COI removal.
- Accelerated mass removal to reduce treatment time and accelerate site closure.
- Simultaneous in-situ treatment of vadose zone, capillary fringe and groundwater.
- Minimally invasive and non-disruptive to site conditions;
- Enhanced groundwater treatment due to the ability of the GCW system to create vertical and horizontal components of groundwater flow.
- Stimulation of natural attenuation processes (aerobic or anaerobic) for more rapid treatment of down-gradient plume COI.
- Effective mechanism for adding nutrients and oxygen for stimulating bioremediation.
- Very low energy requirements.
- Low operation and monitoring requirements.
- Demonstrated effectiveness at over 500 related sites.
- Systems can be modified such that there is no aeration and the in-situ groundwater circulation serves to mix and distribute amendments to enhance reductive dechlorination processes.
- In-well aeration also results in the addition of oxygen to the groundwater that is returned to the aquifer and circulated throughout the formation. Combined with the overall mixing effect, this serves to enhance the rate and extent of in-situ, aerobic biodegradation of susceptible organic COI.
- In the case where anaerobic conditions are desired (e.g. reductive dechlorination of solvents), the stripping can be done under closed-loop conditions so that no air is introduced (except in the early stage of start up).