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Pregledni članak

GROUNDWATER QUALITY AND OBSERVATION WELLS

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Key-words: Groundwater, Pollution, Screen, Casing, Well, Drill Hole, Detection.

Groundwater in the aquifers in river valleys is the most important resource for supply of drinking water in many regions. There are intensive human activities, such as construction and operation hydro-electric power and industrial plants, forest clearance, irrigation and cropping of land, water supply and sanitation works, and particularly the accidental pollution in one town or country can reduce water availability to itself, and to another (downstream) town or country.

Observation wells are not commonly used for sampling of groundwater, but in many instances it may still be the only way to collect sample of groundwater. This paper deals with the construction of observation wells installed and developed in confined or unconfined aquifer to observe and monitor time depending data, such as water level, groundwater quality and indications of contaminant transport in groundwater flow.

Ključne riječi: Podzemna voda, Zagađenje, Filter, Zaštitne cijevi, Zdenac, Bušotina, Detekcija.

Podzemna voda u vodonosnicima u dolinama rijeka najvažnija je zaliha pitke vode u mnogim regijama. U porječju su intenzivne ljudske aktivnosti kao što su industrijski pogoni, sječa šume, natapanje i uzgoj usjeva na tlu, opskrba vodom i sanitarni objekti, te posebni izvanredni slučajevi zagađivanja u jednom gradu ili državi koji mogu umanjiti svoje raspoložive količine vode i količine vode u nizvodnim gradovima i državama.

Opservacijski zdenci se ne koriste isključivo za uzimanje uzoraka podzemne vode, a u brojnim slučajevima to je jedini praktični način uzimanja uzoraka podzemne vode. Ovdje se izlaže o izvedbi opservacijskih zdenaca u vodonosnicima s tlakom, izvedenim radi opažanja i praćenja tijekom zadanog vremenskog razdoblja relevantnih podataka kao što su razina podzemne vode, kakvoća i indikatori zagađivanja koje podzemni tok vode transportira.

Introduction

Some of activities in basin may increase cost of making water suitable for different uses, and destroy, degrade or deplete its valuable ecosystems and species downstream in the basin. Therefore, any international river needs an international river authority. If the countries continue to develop and use the river based only on national priorities, it is bound to come to hard conflict in the not too distant future (U N E P, 1991). International river authority shoud establish an adequate system of stations with wells in all basin to observe and monitor consequences of water uses in all riparian states.

Principle 21 adopted by the United Nations Conference on the Human Environment reflects the context of the principle of good-neighborliness well established in the principle of namely, *»sic utere tuo ut alienum non laedas«* – use your property and perform your activities without damage to other (U N E P, 1991/5)). Groundwater observation wells have a long tradition to be used to observe and monitor of water level. They may be used also to detect or define movement of a spilled or leached substance in groundwater. Designer of an effective observation well should consider the lithologic profile, purpose of observation and monitoring, depth of water table, dimensions of available installation and observation equipment and period of required observations.

Classification of the observation wells could be based on their purpose, design, way of construction, depth and diameter of drilling, application of installed material and/or equipment, etc. This paper deal with design, location, and construction of observation wells, installation and development of well screen in confined or unconfined aquifer. Location and design of observation wells should be convenient groundwater flow, groundwater quality, property of aquifer, and potential contaminant sources location. Observation wells should be equipped for an early indication of pollution in aim to take preventive steps to avoid long-term and widespread contamination of the groundwater and soil. Therefore important part of groundwater quality observation is sampling techniques and sampling frequency.

Contamination of groundwater

The amount of water in the earth biosphere is almost constant today (and in the future), but the number of people that have to use water is not constant. We have to learn more about taking better care of water resources and its use. The second conclusion adopted by the first Croatian Conference on the Waters states that: *»...Quality of water sources is basic issue to facilitate long-term sustainable national economic development«* (H K V, 1995). Water sources do not have to be neither depleted nor polluted. Effective control of water sources, monitoring and evaluation of water quality and quantity should ensure the sustainable use of water for a long future.

Contaminant sources could be as: point, non-point, linear, continental, and the global extension of chemical (organic and anorganic), microbial and physical variety. Wide range of human activities such as: urbanization, industry, agriculture, and mineral extraction are likely to generate some contaminant load. It is often found that just a few are responsible for the major groundwater pollution risk in a given area. Therefore, it is needful to analyze four semi-dependent characteristics of subsurface contaminant load for each activity (F o s t e r, 1987):

- the class of contaminant involved,
- the intensity of contamination,
- the mode of contaminant disposition to the subsurface,
- the duration of application of the contaminant load.

The concentrations of nitrates, phosphates, and some other pollutants have increased in river Drava, Sava, Neretva and in many transboundary watercourses and international lakes, due in particular to the growing use of the fertilizers, detergents and substances to protect crops. Quality of groundwater in many old wells in Sava basin (Zagreb) and in few wells in Drava basin (Varaždin) does not satisfies standard, and those wells are out of use.

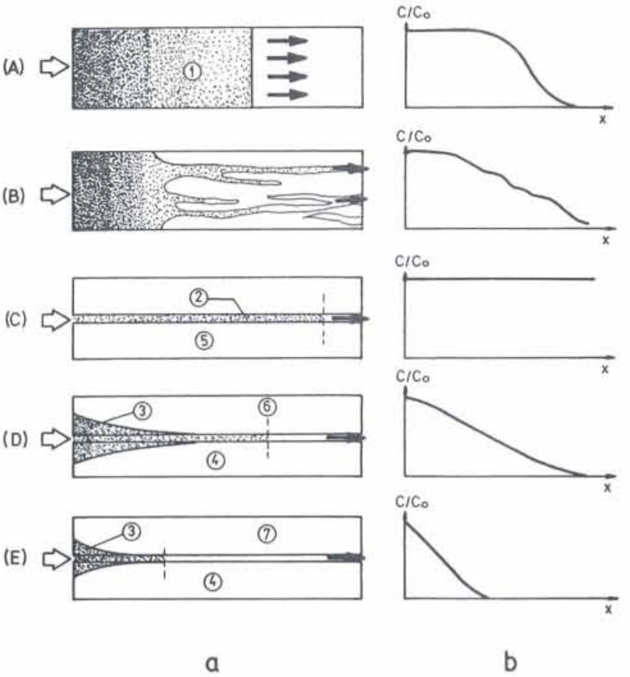

Fig. 1. Contaminant transport, dispersion and attenuation in aquifers:
(A) homogenous uncosolidated,
(B) layered,
(C) fissured,
(D) and (E) porous fissured.
(a) groundwater flow-contaminant transport – schematic, and
(b) relative concentration of contaminant in groundwater flow direction (Foster & Gomes 1989).

Land has been often used as a recipient treatment of industrial wastes (Aluminum factory–Mostar, Herzegovina). It is also used as a dispozal site for city's solid wastes. The percolating industrial wastes from the former and the leaches from the solid wastes contribute to groundwater pollution. These concerns highlight the need for more observation wells to monitor the reliable data related to groundwater, particularly in Neretva basin where water is used for drinking, breeding of fish and irrigation without any treatment.

Groundwater flow is responsible for contaminant transport within and aquifer. A persistent contaminant will tend to migrate with groundwater flow, by so-called convection or advection. Hydrodynamic dispersion and molecular diffusion, from areas of high (C) to low contaminant concentration (C_0), regardless of the direction of the hydraulic pressure gradient, lead to reductions in contaminant concentration and longitudinal spreading of contaminants fronts (Fig. 1A).

Where permeability layering or heterogeneity is present within an aquifer, hydrodynamic dispersion will increase markedly (Fig. 1B). In formation with continuous well-developed fissures of simple geometry and other wise low porosity, contaminant transport will be essentially adecative with only limited hydrodynamic depression accompanying fissure flow (Fig. 1C). In some cases, such as chalky limestones and unwelded volcanic tuffs, matrix porosity may be very large. In such formations contaminant transport rates can be greatly reduced as a result of molecular diffusion into and out of the water stored in the porous matrix (Fig. 1D). Certain contaminants are sorbet onto surfaces of clay minerals available in aquifer, and there the rate of contaminants will be greatly retarded with respect to the groundwater flow (Fig. 1E).

The normal means of access to the subsurface water for sampling are boreholes or wells, because groundwater systems are much more complex and much less accessible than surface water bodies. The complexity of groundwater flow, quality and contaminant transport regime require special hydrogeological expertise in order to design the network, locate and design observation wells, and install equipment to ensure monitor and interpret of the required data.

International river basins

At least 214 river basins in the world are considered as multinational*: 155 of these are shared between two countries; 36 among three countries; and the remaining 23 among four to 12 countries (UNEP 1991/5). The effective use of the international watercourses always depended on cooperation among the riparian States. International treaties and organizations were created in the middle of the eighteenth century to regulate and manage navigation on the Rhine and the Danube rivers, and the Boundary Waters Treaty of 1909 was signed by Canada and the United States to regulate the use of the waters of the Great Lakes.

The international river valleys are the most important resources for supply of water in many regions. Intensive use of water there for industrial purposes, irrigation and cropping, water supply and sanitation works cause pollution as a result of human activities or accidental pollution (war). It could reduce water quality, increase cost of making water suitable for various purposes, and destroy, degrade or deplete its valuable ecosystems and species.

The Principle 21 adopted by the United Nations Stockholm Conference (use your property and perform your activities without damage to others) on the Human Environment in 1972 states that: »States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental polices, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of their States or of areas beyond the limits of national jurisdiction.« (UNEP, 1991/5).

Treaties of shared water resources to regulate the common use exist for virtually all international river basins and lakes. As of 1972, 27 treaties exist in Africa, 38 in Nort and Central America, 31 in South America, 31 in Asia and 175 in Europe (CNRE, 1978). Most of these treaties dealt with issues: allocation of water shares, regulation of navigation and fishing, construction of public works such as barrages, etc. Republic of Croatia will also establish the relevant commissions and treaties with each concerned neighbor countries for the all joint rivers. The commissions will implement the treaty and sort out any conflicts that may arise from the use of the shared water resource.

Groundwater Quality Control Program (**GWQCP**) was initiated by the United Nations Environment Programme (UNEP). GWQCP operates a Global Environment Monitoring System (**GEMS**) at international and local level since 1974. One of the objectives of GEMS is water quality monitoring as a basis for the assessment of the incidence and long-term trends of water pollution by selected persistent and hazardous substances (Vrba, 1991).

*That number was before of USSR, CSR and SFRY disintegration.

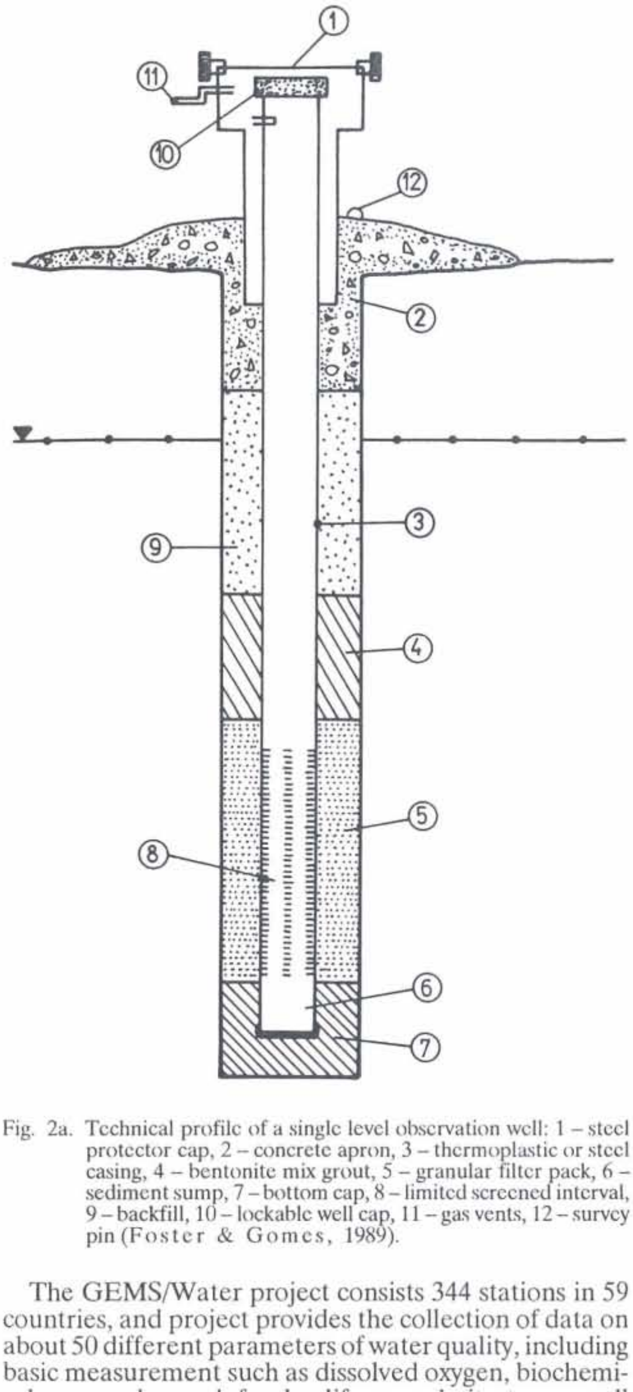

Fig. 2a. Technical profile of a single level observation well: 1 – steel protector cap, 2 – concrete apron, 3 – thermoplastic or steel casing, 4 – bentonite mix grout, 5 – granular filter pack, 6 – sediment sump, 7 – bottom cap, 8 – limited screened interval, 9 – backfill, 10 – lockable well cap, 11 – gas vents, 12 – survey pin (Foster & Gomes, 1989).

The GEMS/Water project consists 344 stations in 59 countries, and project provides the collection of data on about 50 different parameters of water quality, including basic measurement such as dissolved oxygen, biochemical oxygen demand, fecal coliform and nitrates, as well as analyses of chemical trace constituents and contaminants such as heavy metals and organic micro-pollutants (UNEP, 1991).

The Drava and Danube river water (basin) in Croatia will be utilized within the framework of the already undertaken activities, and the principles for the long-term planning in the region. There are possibilities for the realization of the approved concept, and discussion with the Hungarian partners some other solutions (Beraković & Maričić, 1995). Both countries have interest to improve and monitor the quality of water, reduce erosion and flood, facilitate reclamation of surrounding agricultural land, utilize river water for water supply, fishery, sport, recreation, production of power, and monitoring the quality of water in the basin.

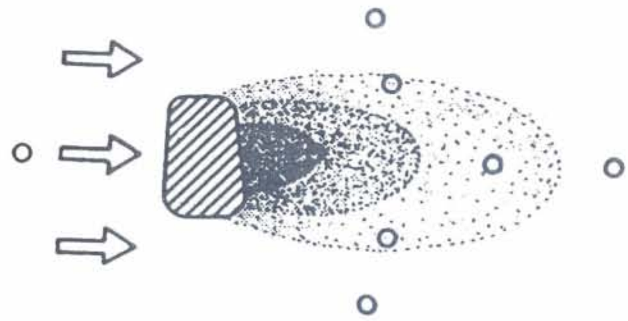

Fig. 2b. Contaminant spreading-scheme monitored using 7 observation single-level wells (Foster & Gomes, 1989).

»There are grave public health risks resulting form water abstracted from the river Danube in countries downstream of Croatia (war) ... The fragile ecology of the Danube delta, which supports many species of fish and birds, is also in risk. Even the fishing industry of the Black Sea could be effected«, stated Mervyn Richardson UNIDO consultant, who undertook an environmental study there (Mihalić, 1993). The environmentalists should estimate the impact of War operation on the very fragile ecology within Neretva delta getting water from all entities in Bosnia & Hercegovina.

The Great Lakes Water Quality Board of the International Joint Commission (**IJC**), for example, has identified some **450 toxic compounds** in the Great Lakes. Some ad hoc actions have been successful in reducing the concentrations of a few compounds, for example DDT (Dichlorodiphenyltricloroethane), PCB (Polychloririnated biphenyl) lead and mercury compounds. In the frame of the Protocol for the protection of the Mediterranean sea against pollution, adopted at Barcelona, an adequate commission and treaty should be established, and implemented in Neretva basin.

Design and equipment of observation wells for various purposes

Main purpose of observation wells, as distinguished from investigation, production and injection drill holes, is survey and monitor of changes in groundwater aquifer studied for a required period. Observation wells installed in aquifer and grout curtain to observe and monitor level of groundwater are called piezometer. The investigation (exploration) drill holes are constructed to evaluate the available mineral resources and assess the geotechnical characteristics of soil at the engineering work sites.

Investigation drill holes is usually yielding the core samples, and the core is obtainable in all drilled rocks to give virtually continuous geological record (Goodman, 1993). The core samples of geological formations should be also collected during construction of observation wells and piezometers. This samples, and samples of water provided during drilling and development of observation well may provide good data relate to quality of groundwater and determination of hydrochemical vertical profiling of aquifer.

Production well have usually bigger diameter required for installation of pump or/and other necessary equipment. Pumping test in such a well with regular observation of groundwater level in piezometers may provide reliable date regarding the aquifer-transmissivity, permeability, attenuation capacity, direction of groundwater flow etc.

Construction and use of observation wells (piezometer) have a long and extensive tradition in observation and monitoring of water level during construction and use of irrigation canals, dams, drainage of agricultural land, mines and many other deeper structure (tunnels, pumping station, foundations of harbors, shipping-yards etc). The curtain is monitored with many piezometer and regular observation in the galleries.

Environmental engineering during last 50 years require more an more drill holes to observe and monitor the quality of groundwater near to: traditional sanitary structures, treatment facilities, industrial plants, oil pipelines, fuel and lubricant stores, disposal of toxic wastes and on other locations prescribed according to international, national and local regulations.

Majority of exploratory drill holes for civil engineering works and investigation of mineral resources are slimhole accomplished using diamond drill bits. Other methods may use three-cone drilling, as in petroleum exploration and production drilling. Air-hammer hole drilling, jackhammer drilling, and other noncoring methods of creating blast holes for mining and quarrying are not generally suitable for construction of investigation drill holes. Diameter of drilling bit, drilling roads, casing and equipment depends on purpose of well, its depth and requirement of samples obtained by coring.

The same drilling techiques that are used for waterwell construction or geotechnical investigation can be used for the construction of groundwater observation/monitoring wells. Cable tool percussion and rotary drilling techniques are normally used, and in some cases power augering may be suitable. Whichever drilling technique is used to construct an observation well some degree of modification to the geohydraulic and hydrochemical regime results from:

- contamination of the aquifer with drilling fluids, or
- vertical flows of groundwater within the borehole before its completion for monitoring, as a result of the interconnection of various depths of the aquifer system at different hydraulic pressure (Foster & Gomes, 1989).

Figure 2a shows technical profile of an usual single-level observation well. Observation and monitoring in an adequate number of wells (Fig. 2b) could provide evaluation of long-term contamination spreading in a wide aquifer (Foster & Gomes, 1989).

Figure 3 shows technical profile of an usual multi-level observation well, convenient to detect and monitor contamination spreading in a heterogenous aquifer. Three PVC screen-sets are installed in three different level of aquifer. PVC material had been used for years in the water well industry, it is readily available, and fairly inexpensive.

Drilling operations, installation of screen and casing, development of observation well, sampling equipment may produce changes within and aquifer. Environmental Protection Agency (**EPA**) in United States of America, drafted 1985 a guidance document titled »**RCRA** (Resource Conservation and Recovery Act), Ground Water Monitoring Technical Enforcement Guidance Manual«. The guidance document states that polytetraflouroethilene or Type 316 stainless steel are the materials of choice as screen or casing in new well installations where

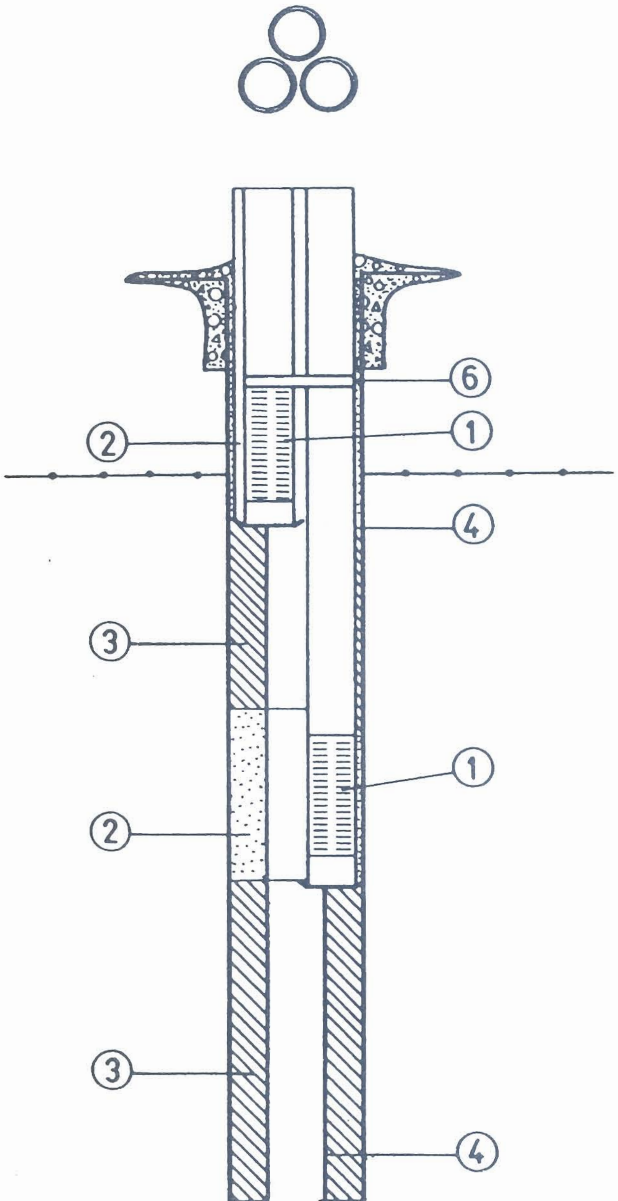

Fig. 3. Technical profile of a multi-level piezometer: – PVC well-screen, 2 – granular filter pack, 3 – bentonite mix grout, 4 – PVC casing (standard OD), 5 – end cap, 6 – concrete apron, 7 – ground-plan of three observation wells (Foster & Gomes, 1989).

volatile organic are the parameters of interest. The EPA has cited a number of reasons why PVC is not an acceptable material for well Construction (Sykes et al., 1986). These include:

- Potential for casing attack and fatigue by exposure to high concentrations of certain organic compounds,
- Desorption of plasticizer and additives from the well casing to otherwise uncontaminated ground water (false positive), and

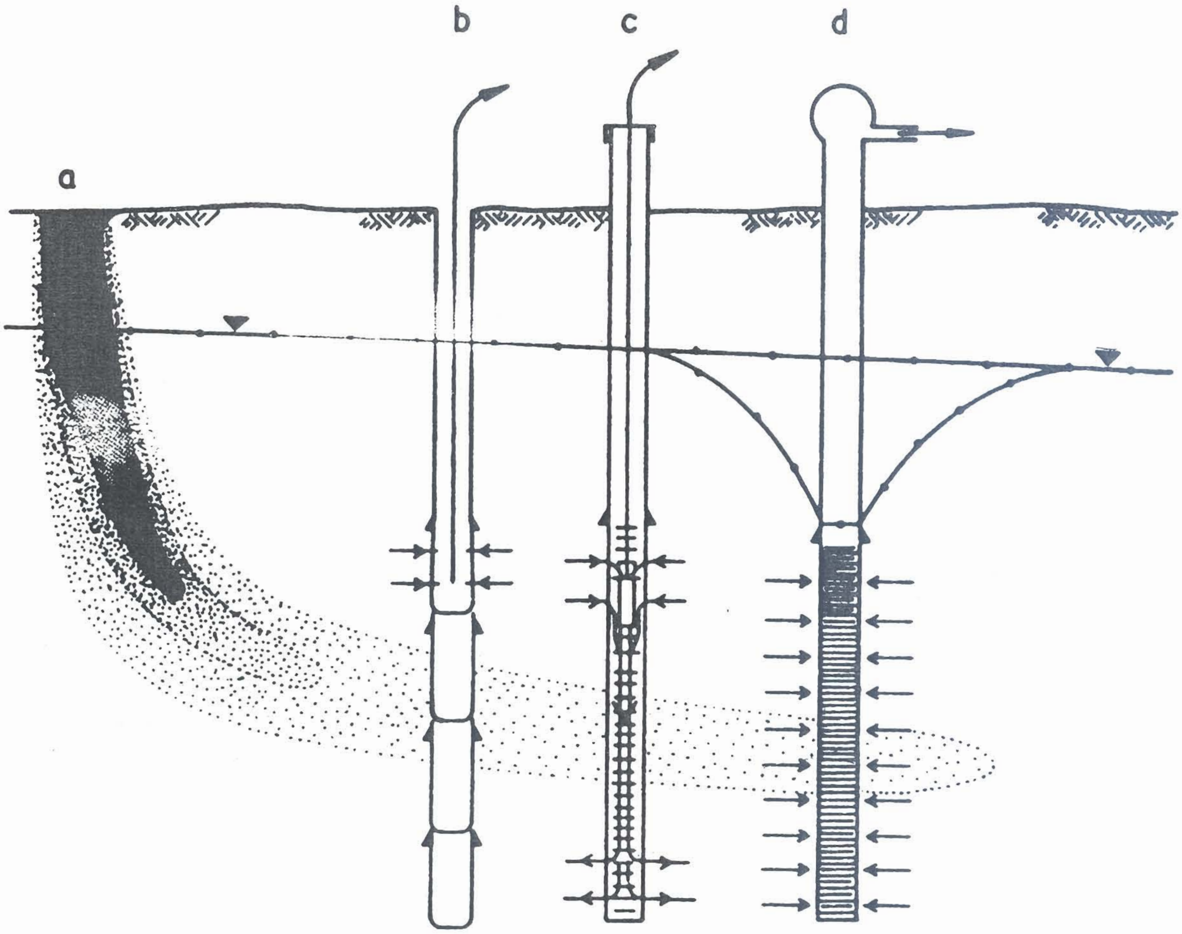

Fig. 4. Collection of Groundwater samples: **a** – pollution point source, **b** – grab from well drilling, **c** – grab from non-pumped well, and **d** – grab from production well discharge (Foster and Gomes 1989).

– Sorption of organic compounds into the well casing exposed to contaminated groundwater.

Inside diameter of casing, screen (slotted casing) and sedimentation pipes (Figs. 2ae. & 3) should accommodate the available submersible pump to clean, develop and provide samples of groundwater for adequate analyses. Croatian institution for standards and measurement (DZNM) (Državni zavod za normizaciju i mjeriteljstvo) should prepare and promote relevant standards (HRN) (Hrvatske norme) for observation wells in aim to provede reliable data convenient for the trustworthy analyses.

Detection of pollution

In cooperation with GEMS/Water project, an adequate number of observation wells and specific monitoring networks should be implemented in all riparian States (new independent) along **Sava, Drava nad Neretva river** and their tributaries. Regular observation and monitoring of all necessary data related to agricultural (non-point), industrial (point), and other pollution should be followed up, and evaluated accordingly.

Groundwater observation wells may be used to detect or define the movement of a spilled or leaked substance in the groundwater. Water table characteristics such as depth, fluctuations and gradient are important factors to consider in the design of an effective network with observation wells.

There have serious limitations in relation to determination of subsurface water quality. Samples of groundwater for analyze in relevant laboratories, could be collected, using main three methods: well drilling (Fig. 4-b), grab from non-pumped well (Fig. 4-c), and production well discharge (Fig. 4-d).

Each of sampling method has some advantages and limitations related to contamination, degassing and atmospheric contact of sample. Illustration of sampling methods and spreading of pollution shows Fig. 4. Inside diameter of interim and lasting casing should enable sampling using air-lift, available bailer, depth sampler, or submersible pump. Groundwater probe system »Insitu« could measure in 50 mm diameter wells important water quality parameters: temperature, pH, specific conductance, dissolved oxygen.

Figure 5 shows a typical observation wells (two) constructed for a service station. Smaller observation well is installed within Tank excavation, and the deeper observation well is installed outside of Tank excavation (Scheinfeld et al., 1986). These observation wells consist of 2-inch (51 mm) PVC casing and screen with slot size of 0.02 inches (0.51 mm).

Beside many devices to detect the hydrocarbons in observation wells, there are on the market many devices manufactured to detect the presence of many other chemical, microbial and physical contaminants in groundwater aquifer. Desirable characteristic of a released detection system in observation wells (Scheinfeld et al., 1986) include:

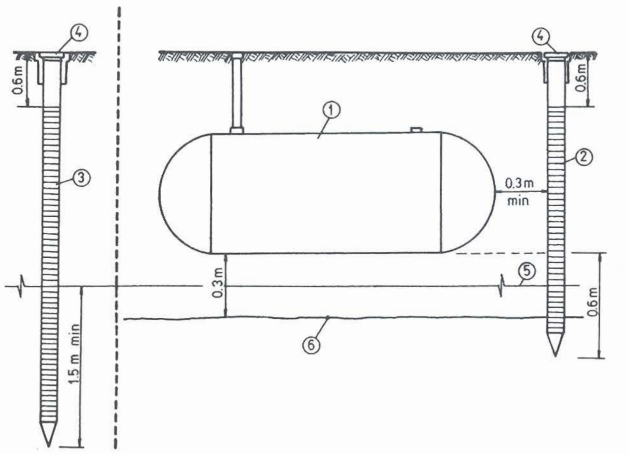

Fig. 5. Observation wells installed near pollutant stored in a tank (Scheinfeld et al., 1986): 1 – Tank with pollutant, constructed as per manufacturer Specification, 2 – well screen in tank excavation, 3 – well screen (0.020 mm slot) outside tank excavation, 4 – waterproof cap, 5 – water table, 6 – bottom of tank excavation.

- Suitability for existing application,
- Ability to detect unconfined liquids,
- Simple, safe and reliable design,
- Maintenance-free operation,
- Ability to screen out false alarms,
- Cost-effective performance, and
- Tamperproof and secure design.

The principal criteria of any release detection system is the rapid detection of a loss of material from the containment system. Early detection could be observed in the observation well having its screen installed in an appropriate interval and installed and adequate detection instruments will facilitate a rapid corrective response.

Recommendation

Some of activities in basin may increase cost of making water suitable for different uses, and destroy, degrade or deplete its valuable ecosystems and species in teh basin. Several steps are opportune to be undertaken as soon as possible.

1. The available framework of the already undertaken activities, and the principles for the long-term planning in the basins of our shared rivers, should be applied and improved. The improvement of the present development concept and its reflection on the environment there, should be further analyzed and discussed with the relevant partners.

2. In close cooperation with GEMS/Water project, along **Sava** and **Drava** rivers and tributaries, and particularly **Neretva** basin, a regular observation system should be established for permanent monitoring and evaluation process in the order to protect environment in the long-term interest of all population in the basins. Therefor, the density of observation wells and sampling frequency should be much more higher to comply with the inter-regional monitoring networks, to control groundwater quality.

3. Croatian institution for standards and measurement (**DZNM**) should design and promote the relevant national standards (**HRN**) for observation station/wells suitable to detect and monitor reliable data related to quality of groundwater and surface water in the basins of our bigger rivers. Detection system there should be simple, safe, cost-effective, tamperproof and suitable for demanded applications, with ability to screen out false alarms.

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