UNIVERSITY OF NOVA GORICA
GRADUATE SCHOOL

# PHYSICAL AND CHEMICAL STATUS AND TOXICITY OF WATER AT THE UPPER BASIN OF RESERVOIR VOGRŠČEK AND ITS TRIBUTARIES AND THE ROLE OF NATURAL WETLANDS AT RESERVOIR INFLOWS

MASTER'S THESIS

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Nova Gorica, 2011

UNIVERZA V NOVI GORICI
FAKULTETA ZA PODIPLOMSKI ŠTUDIJ

# FIZIKALNO IN KEMIJSKO STANJE TER TOKSIČNOST VODE ZGORNJEGA JEZERA ZADRŽEVALNIKA VOGRŠČEK IN NJEGOVIH PRITOKOV TER VLOGA NARAVNIH MOKRIŠČ NA VTOČNEM DELU ZADRŽEVALNIKA

MAGISTRSKO DELO

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Nova Gorica, 2011

*Z leti sem počasi spoznal, da se nobena stvar ne zgodi naključno – nasprotno, vsak dogodek ima svoj zakaj in svoj zato.*

*(Tomaž Humar)*

# ABSTRACT

The reservoir Vogršček is situated in western Slovenia, in a rural area within the lower part of Vipava valley. The region has a strong agricultural background, supported mainly by viticulture, agronomy and fruit-growing. The reservoir was built in the late 80-ies to mitigate the impacts of extreme draughts and floods and it serves as water storage for irrigation of cultivated areas and for flood wave control. Before the reservoir was put up, a highway dam was built within the reservoir area, which divides the reservoir water body in two parts - the smaller upper basin and the bigger main basin. Both basins were reported to show signs of eutrophication on several occasions in the past twenty years. The major concern was focused on the upper basin, since it is the major recipient of surface waters from surrounding area.

The aim of this study was to determine a possible impact of anthropogenic activities within the reservoir Vogršček drainage area, such as domestic wastewater discharges and agricultural practices, on water quality at the reservoir upper basin and its inflows. Major stream inflows and some melioration ditches were monitored together with the upper and main basin. We also wanted to research about the possible buffering capacity of the two major natural wetlands, which have developed at the upper basin. Field work, sampling and laboratory analyses followed the standard methods adopted for water quality monitoring and assessments. Measurements of water and air temperature (T), pH, electrical conductivity (EC), dissolved oxygen (DO) and dissolved oxygen saturation were carried out *in situ*. Chemical oxygen demand (COD), biochemical oxygen demand ($BOD_5$), and $NH_4^+$ determination were done by method of photometric determination. Total organic carbon (TOC) measurements were done by differential method. Measurements of cations ($Ca^{2+}$, $Mg^{2+}$, $K^+$, $NH_4^+$, $Na^+$) and anions ($F^-$, $Cl^-$, $Br^-$, $NO_2^-$, $NO_3^-$, $SO_4^{2-}$, $PO_4^{3-}$) concentrations were performed by the method of ion chromatography. Toxicity was analysed with the luminescent bacteria test. Results of EC, COD, $BOD_5$, and TOC variables suggested a possible organic matter overload at the inflows and at the upper basin. The results of nitrate-nitrogen ($NO_3$-N) concentrations suggested a possible anthropogenic impact on reservoir inflows. The toxicity measurements showed presence of possible toxic elements for living organisms at some locations on few occasions. In general the results of present study exhibited a tendency toward water quality aggravation at the reservoir and its inflows in the period of last twenty years. Wetlands exhibited an undefined position suggesting that their buffering capacity and their role within the reservoir ecosystem should further be investigated.

Key words: reservoir, Vogršček, water quality, wetland, buffer zone

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| | |
|---|---|
| ARSO | Agencija Republike Slovenije za okolje - Environmental Agency of the Republic of Slovenia |
| a.s.l. | above sea level |
| BOD | biochemical oxygen demand |
| $BOD_5$ | biochemical oxygen demand in five day period |
| COD | chemical oxygen demand |
| DO | dissolved oxygen |
| DWD | Drinking Water Directive (Directive 98/83/EC) |
| EC | electrical conductivity |
| EU | European Union |
| GKY | Gauss Krüger coordinate Y |
| GKX | Gauss Krüger coordinate X |
| LOD | limit of detection |
| main basin | bigger and main part of the reservoir Vogršček water body |
| MONG | Mestna občina Nova Gorica - Municipality of Nova Gorica |
| MOP | Ministrstvo za okolje in prostor - Ministry of Environment and Spatial Planning |
| $NO_3$-N | nitrate nitrogen |
| operator | Hidrotehnik d.d. – the operator of the reservoir Vorgrščček |
| TDS | total dissolved solids |
| TN | total nitrogen |
| TOC | total organic carbon |
| TP | total phosphorous |
| UK | United Kingdom |
| upper basin | smaller north-eastern part of the of reservoir Vogrščček water body divided from the main basin by a highway dam |
| ZZVNG | Zavod za zdravstveno varstvo Nova Gorica - Institute for Health Care Nova Gorica |
| WFD | Water Framework Directive (2000/60/EC) |

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# 1 INTRODUCTION

The Vogršček reservoir is situated in western Slovenia, in a rural area within the lower part of Vipava valley. The region has a strong agricultural background, supported mainly by viticulture, agronomy and fruit-growing. The valley has formed in Eocene flysch layers (Trček, 2005) and is named after its main watercourse - the Vipava River. The climate of this region is Sub-Mediterranean, meaning that is characterized by strong Mediterranean influence with air temperatures and rainfalls, which are above the Slovenian average (Luznik and Vrhovšček, 1992). These climate characteristics in combination with low-permeable (flysch base) soils resulted in alternating periods of extreme draughts and floods, which had a huge impact on agricultural gain in the past (Luznik and Vrhovšček, 1992). The Vogršček reservoir was built with the intention to mitigate these impacts, and serves as water storage for irrigation of cultivated areas, and for flood wave control (Bratina et al., 1981). The reservoir was built in the late 80-ies by placing a barrier on the Vogršček stream, which is a right tributary of the Vipava River. The direct cause of flood barrier construction was that part of the Vogršček stream drainage basin area was flooded. The flooded area was not populated and consisted of meadows, grassy vegetation, and forest (Dokumentacija …,1983).

Before the barrier was completed and the reservoir was built up, a highway dam was built within the reservoir area, which divides the actual reservoir water body in two parts – into the north-eastern smaller "upper basin" and the bigger "main basin" *(Figure 1.1)*. The upper basin serves mainly as a recipient of the Vogršček stream and other inflows originating from the surrounding rural area, while the main basin serves as major water storage for irrigation purposes.

***Figure 1.1: A view on the reservoir Vogršček and its surroundings from the north; upper basin and the highway are visible on the left and the barrier on the right part of the picture (photo: D. Fučka)***

Both basins were reported to show signs of eutrophication on several occasions in the past years (Luznik and Vrhovšek, 1991, 1992; ARSO, 2007, 2008, 2009, 2010). The major concern was focused on the upper basin, since it is the major recipient of surface waters from surrounding areas, which includes villages, single households, traffic connections, and agricultural land (Kontič and Gabrijelčič, 2000; Vrhovšek and Vovk Korže, 2009). A publication suggested that these loads influenced the development of two major natural wetlands that have formed within two embayments at the upper basin (Vrhovšek and Vovk Korže, 2009). It was deduced that the wetlands have the capacity of buffering the inflowing loads, and mitigate the pollution impact carried out on the upper basin from the drainage area. Despite all concerns about the supposed impacts that could seriously compromise the reservoir water quality and its ecological state, neither accurate study was performed to determine the actual impact of anthropogenic activities within the drainage basin on the reservoir nor any attempts were made to mitigate possible impacts from agricultural activities and settled area. In fact, the only one water quality monitoring at the inflows of the reservoir upper basin was performed almost twenty years ago (Luznik and Vrhovšek 1991, 1992). All other water quality monitoring that was carried out was focused on the reservoir water body, i.e. main and upper basin (ARSO, 2007, 2008, 2009, 2010; Monitoring površinskih voda..., 2007, 2008, 2009, 2010, 2011; Poročilo o preskusu, 2007, 2008, 2009, 2010).

## 1.1 Previous Research and Water Quality Monitoring Reports

The major purpose of the Vogrščcek reservoir is water supply for irrigation. Consequently, water quality variables have to meet the determined standards for irrigation use (Mejne vrednosti parametrov…, Ur. l. RS, št. 84/2005, 62/2008 in 113/2010). Water quality monitoring has been carried out on a quite regular basis at the reservoir throughout the twenty years and the data are collected in the following reports:

- Kontič and Gabrijelčič (2000); the authors had reviewed the reports of water quality data obtained in the first decade of the monitoring period from 1989 to 1999. In the report they processed the water quality data collected at four locations, i.e. one at the upper basin, two at the main basin, and one at reservoir floor outflow. They concluded that in the examined period the water quality monitoring was performed correctly but not consistently and that it should include sapro-biological analyses.

- Poročilo o preskusu (2007, 2008, 2009, 2010); the water quality monitoring data at the Vogrščcek reservoir for the period between 2003 and 2010 were collected in reports for each year by the Institute for Health Care Nova Gorica (abb. ZZVNG) (Poročilo o preskusu, 2007, 2008, 2009, 2010). The water quality monitoring was financially supported by the operator of the Vogrščcek reservoir and was carried out usually once a year at four locations, e.i. at the upper basin, at the main basin, at the floor outflow, and at the hydrant Šempeter.

- ARSO (2007, 2008, 2009, 2010); in order to meet the requirements of the European Water Framework Directive (2000/60/EC; abb. WFD) and Slovenian legislation requirements (Zakon o vodah (Water Act), Ur. l. RS, št. 67/02, 110/02-ZGO-1, 2/04-ZZdrl-A, 41/04-ZVO-1, 57/08; Uredba o stanju površinskih voda (Decree on surface water status), Ur. l. RS, št. 14/2009, 98/2010) a second water quality monitoring has been carried out at Vogršček reservoir since 2003, financially supported by the competent state service - Environmental Agency of the Republic of Slovenia (abb. ARSO). The water monitoring data are collected and published in annual reports by ARSO (ARSO, 2007, 2008, 2009, 2010). Monitoring was regularly performed at one main basin location, with the exception for the year 2006, when it was done also at one upper basin location.

- Spremljanje kvalitete voda v čezmejnem območju (Water quality monitoring in the border area - professional project report) (2005); water quality monitoring was performed at Vogršček reservoir in 2004 and 2005 in the context of an international Slovenian-Italian Phare-Program directed by the Municipality of Nova Gorica (Slovenia) (abb. MONG) in cooperation with Municipality of Gorizia, (Italy).

- Monitoring površinskih voda…(The water quality monitoring of the surface waters…) (2007, 2008, 2009, 2010, 2011); after the Phare-Program which finished in 2005 MONG financially supported a regular water quality monitoring twice a year. The monitoring was performed by ZZVNG at one upper and one main basin location and the data are collected in the named reports.

- Birsa and Srebrnič (2001); the authors performed one-term water quality analyses at Vogršček reservoir for the purpose of a term paper completion.

- Limnos d.o.o. (2000); water quality data were collected in the context of a project appointed “Possibilities for a Multipurpose Use of the Vogršček reservoir”. The project was never concluded.

In all cited reports, the results of the monitored water quality variables were processed and presented according to the national legislation requirements in force at the time when the respective study and report was performed. The Vogršček reservoir was usually reported to show signs of eutrophication which varied annually (ARSO, 2007, 2008, 2009, 2010). According to the reported water quality data the Vogršček reservoir alternates between eutrophic and meso-eutrophic state.

However, all listed water quality monitorings were restricted to the upper and main basin of the reservoir and did not include any of the reservoir inflows or any of the streams and melioration ditches that gravitate towards the upper and main basin. In fact, water quality monitoring of the reservoir inflows was carried out only in 1991 and 1992 (Luznik and Vrhovšek, 1991, 1992). The purpose of the study was to monitor the major reservoir inflows, including one melioration ditch, for a one-year time period. They did not report the exact number of samplings that were carried out. All in all, they concluded that the inflows of the upper basin showed significant signs of organic pollution.

## 1.2 Aim and hypothesis

The aim of this Master thesis is to determine a possible impact of anthropogenic activities within the Vogrščček reservoir drainage area, such as domestic wastewater discharges and agricultural practices, on water quality variables at the upper basin and its inflows. According to Luznik and Vrhovšek (1991, 1992) the inflows showed increased nutrient loading, in view of phosphate and nitrate concentrations, and critical microbiological-sanitary conditions. Despite these observations, any additional monitoring of water quality of the reservoir major inflows or small melioration ditches that gravitate towards reservoir from the surrounding crops and vineyards was never carried out again. The necessity of a regular water quality monitoring at the reservoir inflows was reminded also by Kontič and Gabrijelčič (2000) who suggested that possible sewage effluents and agricultural run-off impacts on the reservoir water quality and its ecological state should be assessed. Furthermore, in the publication of Vrhovšek and Vovk Korže (2009) the authors stated that wastewaters effluents from the village Osek and other single households combined with agricultural surface run-offs within the reservoir drainage area are the major source of pollution of the Vogrščček stream which inflows in the upper basin. They also stated that north-eastern marginal part of the upper basin has developed into a wetland as a result of Vogrščček stream impacts. Thus, the wetland functions as mitigation zone and buffers the inflow loads after they have entered the upper basin. Based on the cited statement we aimed to research the possible buffering capacity of the two major natural wetlands, which have developed at the north-eastern marginal part of the upper basin. Since the last and the only water quality monitoring at the inflows of the upper basin was carried out almost twenty years ago, we compared the results obtained from our study with the results and observations from the year 1992 (Luznik and Vrhovšek, 1992). On this basis we attempted to determine a possible trend of measured water quality variables at the upper basin and its inflows for the twnty year period.

Following hypotheses were set down:

1. Anthropogenic activities within the Vogrščček reservoir drainage area, such as domestic wastewater discharges and agricultural activities, affect the water quality of the upper basin and its inflows, including melioration ditches which gravitate towards the upper basin.
2. Natural wetlands, which have developed at the north-eastern marginal part of the upper basin, have the capacity to mitigate impacts of the upper basin inflows and act as a buffering zone between the inflowing loads and the upper basin.

# 2 LAKE AND RESERVOIR LIMNOLOGICAL CHARACTERISTICS - THEORETICAL BACKGROUND

A number of characteristics differentiate running surface waters, rivers and streams from lake and reservoir ecosystems. Running freshwater environments are called lotic (lotus, from lat. *lavo*, to wash) for obvious reasons of unidirectional water movement along a slope in response to gravity (Wetzel, 2001). Lotic ecosystems are contrasted to lentic (lat. *lenis*, to make calm) or lake ecosystems. However, while lakes and reservoirs are relatively more 'closed systems' than rivers and streams, they are far from being isolated. Most lakes and reservoirs are open and have distinct flows into, through, and out of their basins (Wetzel, 2001). The distinction between lotic and lentic ecosystems focuses on the relative residence times of the water (Pepper et al., 2006). Lakes across the planet have an average retention time of 100 years. Running waters, on the other hand, have a much shorter retention time, i.e. for rivers from 10 to 30 days (Brilly and Šraj, 2005; Pepper et al., 2006). The short retention time in streams and rivers means that pollutants are transferred rapidly to downstream areas, lakes, groundwater or oceans. Relatively long retention time in lakes and reservoirs on the other hand, highlights the danger of introducing pollutants that will be present for a longer period of time (Pepper et al., 2006). Although some lakes and reservoirs have subterranean groundwater inputs, the majority of water entering them is a result of overland flow, therefore lakes and reservoirs are reflections of all processes that have occurred in the watershed up to that point (Wetzel, 2001). Consequently, both natural and anthropogenic watershed influences can have profound effects on water quality for human use and aquatic communities living within lentic systems (Wetzel, 2001; Pepper et al., 2006).

Humans have created artificial lakes by damming streams for at least 4000 years. Only in the last two centuries, however, has this activity become significant for the purposes of flood control and the provision of power and water supplies for urban and rural populations (Wetzel, 2001). Reservoirs are being constructed on an unprecedented scale in response to the exponential demands of humans. Most of them are constructed without much environmental concern; especially massive alterations of large drainage systems that will result in major modifications in topography and regional climate are not yet fully recognized or even partially understood (Wetzel, 2001).

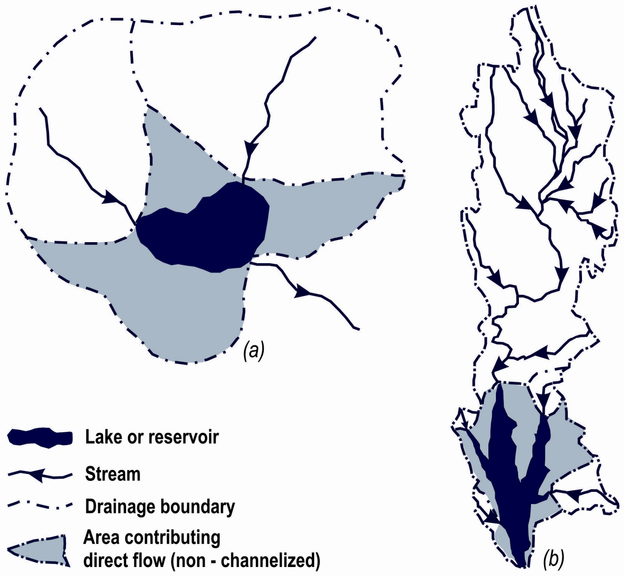
Much of scientific limnological understanding originates from natural lake ecosystems, and study of reservoir ecosystems indicates many functional similarities between artificial and natural lakes (Wetzel, 2001). On the other hand, reservoirs differ in some significant ways from natural lake ecosystems. In their nature reservoirs occupy an intermediate position between rivers and natural lakes and they are often described as 'river-lake hybrids' (Kimmel et al., 1990), regarding to their limnological characteristics. However, the basic difference that influences the reservoirs limnological characteristics and their response to external and internal impacts is in their anthropogenic origin; they are manufactured by humans for anthropogenic needs, while lakes have natural origins (Pepper et al., 2006).

## 2.1 Climate

Reservoirs are constructed predominately in regions where water is needed for human use, and where large natural lakes are sparse, or unsuitable for human exploitation (Wetzel, 2001). In these regions climate tends to be warmer than is the case in regions with many natural lakes, resulting in higher average water temperatures, longer growing seasons, and precipitation inputs that are usually less than evaporative losses (Thornton, 1990a).

## 2.2 Drainage basin

Reservoirs are most frequently constructed by damming a river valley, within which water accumulates behind the dam. Water released downstream is regulated according to water inputs from the drainage basin as well as uses of the water. Reservoirs usually have the greatest proportion of the drainage basin located upstream from the impoundment. In general, the stream order and size of drainage basin upstream from reservoirs are higher and larger, respectively, than for lakes (Thornton, 1990b). In case of natural lakes many streams and several major rivers originate from headwater lakes, i.e. a characteristic of many glaciated lakes (Thornton, 1990a). These lakes generally have a relatively circular drainage basin and a relatively equitable distribution of inflow around the perimeter of the lake *(Figure 2.1)* (Thornton, 1990b). Reservoirs, however, are generally located near the mouth or base of the drainage basin, a considerable distance below the headwater of the stream *(Figure 2.1)* (Thornton, 1990b). Therefore, reservoirs receive only a small proportion of their total inflow as direct runoff from adjacent watershed, with the majority of the water, nutrient, and sediment load entering from one or two major tributaries located a considerable distance from the dam (Ford, 1990). Reservoir drainage basins are generally narrower and more elongated than lake watersheds *(Figure 2.1)*. The shape and location of the drainage basin may influence the runoff and transport of material to lakes and reservoirs. While the process of drainage basin runoff is similar whether the receiving system is a lake or reservoir, differences in drainage basin characteristics between lakes and reservoirs influence the quantity and quality of material delivered to the system (Thornton, 1990b). Consequently, larger drainage basins associated with reservoirs may result in greater annual flows which enter into reservoirs than is the case within lakes (Thornton, 1990b).



(c)

| | Characteristic | |
|---|---|---|
| **Factor** | **Reservoir** | **Glacial lake** |
| Shoreline | Astatic | Stable |
| Water level | Large, irregular fluctuations | Natural |
| Flushing rate | High | Low |
| Thermal stratification | Irregular | Natural regime, dimitic |
| Ionic composition | Variable | Relatively predictable |
| Sedimentation rate | High | Low |
| Turbidity | High | Low |
| Water release level | Variable | Surface |
| Organic accumulation | Rapid | Slow |
| Principal source of nutrients | Allochthonous, then autochthonous | Autochthonous |
| Growth selection | Rapid (r) | Homestatic |
| Immigration-extinction | Rapid | Slow |

***Figure 2.1: Drainage basin characteristics of (a) lakes and (b) reservoirs (Thornton, 1990b: 44) and characteristics of reservoirs and glacial lakes (c) (Thornton, 1990a: 11)***

## 2.3 Reservoir morphology and zonation

Reservoirs are almost always formed in river valleys, in the base of the drainage basins, and after the confluence of several tributaries, the water body is usually elongated, narrow, and highly dendritic (Ford, 1990) *(Figure 2.2)*. As a result of the common linear morphology in a river valley, distinct physical and biological patterns develop along the longitudinal gradient of reservoirs. According to authors (Ford, 1990; Kimmel, 1990; Thornton 1990a, 1990b, 1998; Wetzel, 2001) a heuristic model is used to describe the development of longitudinal patterns in reservoirs *(Figure 2.2)*. Longitudinal patterns named, a riverine zone, a transitional zone, and a lacustrine zone provide the central focus for reservoir limnological processes and reservoir system responses, by possessing unique physical, chemical, and biological properties.

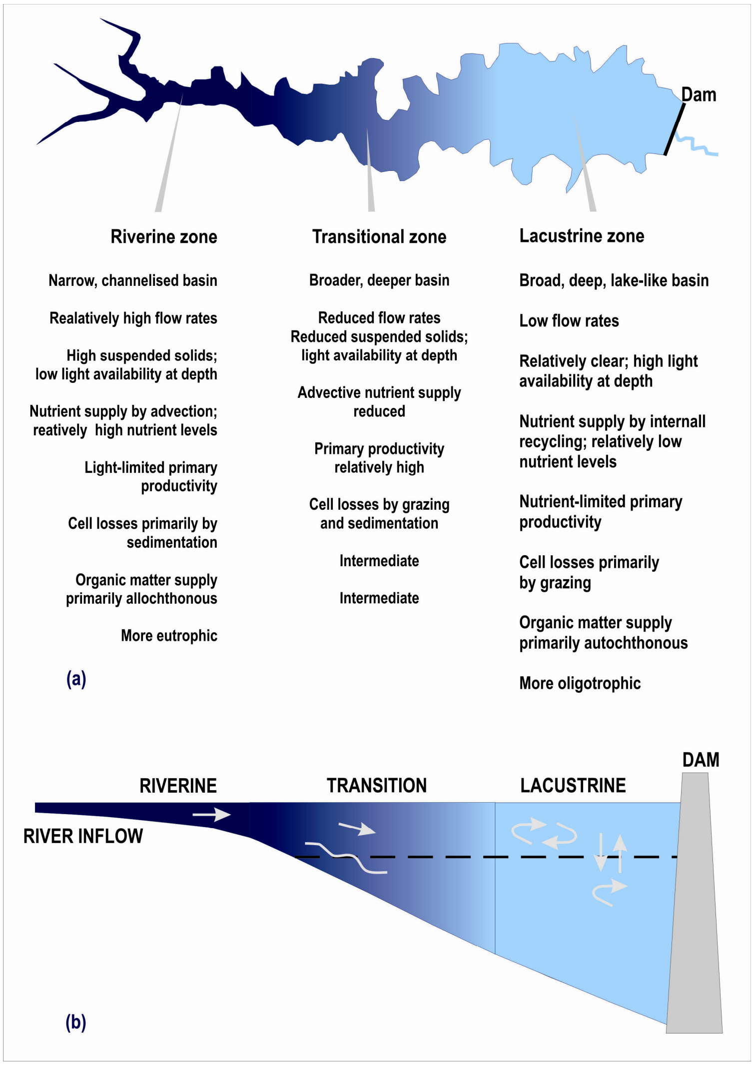


***Figure 2.2: (a) Longitudinal zonation and dendritic morphology of reservoirs (Thornton et al., 1998: 374); (b) Vertical cross-section of generalized zones along longitudinal gradients in reservoirs (Wetzel, 2001: 38)***

The **riverine zone** is often relatively narrow as a result of river geomorphology, and water is usually well mixed (Wetzel, 2001) *(Figure 2.2)*. This is the zone where sedimentation of sand and coarse silt occurs because water velocities decrease as the water enters the reservoir, but advective transport by currents is sufficient to move significant quantities of fine suspended particulates, such as silts, clays, and particulate organic matter (Thornton, 1990b). High particulate turbidity commonly reduces light penetration and limits primary production within the water of this zone (Thorton, 1990a). Loading of organic matter from allochthonous sources is high in proportion to water volume and high decompositional rates often result with high consumption of dissolved oxygen. But, because the riverine zone is generally shallow and well mixed an aerobic environment is maintained (Wetzel, 2001).

In the **transitional zone** riverine water velocities decrease as energy is dispersed over larger areas and an appreciable portion of the turbidity load settles out of upper water strata as a result *(Figure 2.2)* (Wetzel, 2001). The transition zone is the area where silts, coarse-to-medium clays, and fine particulate organic matter settle (Thorton, 1990b). Decreased turbidity results in enhanced depth of light penetration and increased rates of photosynthetic productivity by phytoplankton and, in some shallow reservoirs, from rooted vascular plants (Thornton, 1990a; Wetzel, 2001). Because both light and nutrients are available for algal photosynthesis, the transition zone can be the most productive region within the reservoir (Kimmel et al., 1990).

Within the **lacustrine zone**, characteristics become more similar to lake ecosystems *(Figure 2.2)*. This portion of the reservoir often stratifies thermally and assumes many of the properties of natural lakes in regard to plankton production, limitations by nutrients, sedimentation, and decomposition in the hypolimnion (Wetzel, 2001). The lacustrine zone has sedimentation patterns reflecting the settling of fine clays and colloidal material as well as autochthonous (within-reservoir) production of organic matter (Thorton, 1990b). Concentrations of suspended inorganic particulates are lower and photic layer is deeper (Kimmel et al., 1990). Light penetration is sufficient to promote primary production with the potential for nutrient limitation (Thornton, 1990a). Stratification and water movements can be modified or complicated, both spatially and in time, by hypolimnetic or bottom withdrawal of water at the dam, as is commonly the case (Wetzel, 2001).

It is important to recognize that riverine, transitional, and lacustrine zones are not discrete and invariable entities within a reservoir, but are usually quite dynamic zones which expand and contract in response to watershed runoff events, density flow characteristics, and reservoir operating schedules (Kimmel et al., 1990).

## 2.4 Transport and sedimentary processes

One of the major differences comparing to natural lakes is that a reservoir is always in a dynamic state and is never in equilibrium (i.e. steady state) with the forcing functions (Ford, 1990). Since the stream order above lakes is generally lower than the stream order above reservoirs, reservoirs tend to receive runoff water mainly via high-order streams *(Figure 2.1)*, which results in higher energy for erosion, large sediment-load carrying capacities, and extensive penetration of dissolved and particulate loads into recipient lake water (Ford, 1990). Extreme and irregular water level fluctuations commonly occur in reservoirs as a result of flood inflow characteristics, land-use practices not conductive to water retention, channelization of primary influents, flood control, and large, irregular water withdrawals (Wetzel, 2001). Larger drainage basins and greater flows also indicate the potential for greater sediment and nutrient loads to reservoirs (Thornton, 1990b). All of these impacts result in high, but irregularly pulsed, nutrient and sediment loading, and contaminant transport to the recipient reservoir (Thornton, 1990a). Fluvial sediments are generally enriched in the finer clay and silt particles relative to the contributing watershed soils, since less energy is required to transport these finer particles from the watershed to the stream (Ford, 1990). Moreover, fine silt and clay particles have a high sorptive capacity for phosphorus, dissolved organic acids, and other nutrients or contaminants (Thornton, 1990b; Robards et al., 1994; Wetzel, 2001).

Regarding these properties, according to cited authors and many others, sediment transport and deposition is a dominant process in reservoirs. It significantly influences the ecological response of the system, because it affects biological processes in many complex ways, the most important of which are light and nutrient availability (Thornton, 1990a; Wetzel, 2001). Even more, sediment is not only the major pollutant by weight and volume and the main cause of turbidity, but is also a major carrier and catalyst for pesticides, organic residues, nutrients, and pathogenic organisms (Thornton, 1990b).

Finally, when the inflowing streams and rivers reach the recipient water body the spatial distribution of sediment loading is different between lakes and reservoirs (Thornton, 1990b). In lakes there is generally an equitable distribution of inflow around the periphery of the system *(Figure 2.1)* in reservoirs, however, patterns along the longitudinal gradient (i.e. riverine, transitional and lacustrine zone) condition sediment distribution and deposition within the water body (Thornton, 1990b).

## 2.5 Reservoir operation

Water level fluctuations induced by withdrawals represent a major abiotic stress to reservoir ecosystems. Alternating periods of flooding, dewatering, and resuspension may result in significant transport, exchange, and redeposition of sediments and their associated constituents in reservoirs and enhanced interactions with the overlying water column (Thornton, 1990b; Wetzel, 2001).

The type of outlet structure and reservoir operation plan is totally dependent on its usage. In cases when the outlet structure is closed conduit spillway (overflow) or a siphon, these structures automatically maintain the water surface at a specific elevation (Ford, 1990). This form of surface withdrawal is similar to outflows from natural lakes and has minimal impact on the in-pool mixing (Ford, 1990; Kennedy and Walker, 1990). Much different is in case of bottom release reservoirs. The strength of stratification and the zone of withdrawal (zone of outflow) in case of bottom release may be restricted to the hypolimnion, which results in deeper epilimnion, warmer hypolimnion, and weaker density gradient (Ford, 1990; Thornton, 1990a; Wetzel, 2001). Kennedy and Walker (1990) cited some cases in which hypolimnetic withdrawal resulted in a loss of nutrients from the reservoir and consequent excessive loading of nutrients downstream over the summer stratification period, because nutrients tended to accumulate in the anoxic hypolimnium. In their study Baldwin et al. (2008) reported about periodic pulses of nutrients from hypolimnium to warm surface layer, which stimulated cyanobacterial growth in Lake Hume reservoir during summer extreme drawdown. They emphasized that an understanding of the interactions between the hydrodynamics and the biochemical processes in the sediment operating within a reservoir is crucial to understanding the impacts on water quality within the reservoir. The hypolimnetic withdrawal can, as reported by Cole and Hannah (1990) and reminded by Wetzel (2001), also significantly influence the water temperature and DO concentrations within a reservoir and downstream, resulting in altered loads of nutrients and lake stratification (*see* chapter 2.6).

## 2.6 Dissolved oxygen dynamics

As in natural lakes, the distribution of oxygen and rates of loss are governed by a balance among mixing, inflow intrusions, photosythesis, and losses by oxidative consumption (Wetzel, 2001). The processes are similar among all freshwater ecosystems, but the rates of change in reservoirs are generally much more variable and dynamic than in lakes, due to the complex hydrodynamics, morphology, draw-down and discharge, and other factors (Wetzel, 1990b). For reservoirs most of factors that influence DO concentrations are influenced by characteristics of longitudinal zones, therefore DO concentrations besides changing vertically with depth, change also longitudinally from the riverine zone to the lacustrine zone.

### *2.6.1 Temperature and dissolved oxygen*

The solubility of oxygen increases with decreasing temperature (Wetzel, 2001). The variations in temperature and DO are more pronounced in reservoirs than in natural lakes due to the effects of inflow and outflow on hypolimnetic temperatures; during summer stratification in periods of high outflow in a bottom-release reservoir, the coldest hypolimnetic waters of a reservoir are often discharged and replaced by the warmer layers from above. This results in alternated oxygen concentrations in the hypolimnion and water column, such as e.g. accelerated oxygen depletion and anoxic conditions in the hypolimnium, or even stratification break-down (Cole and Hannon, 1990).

### *2.6.2 Inflows, outflows and dissolved oxygen*

The riverine zone of a reservoir receives incoming water from the parent river, which affects the distribution and concentration of DO within all zones of a reservoir (Cole and Hannon, 1990). The inflow loads and temperature form density currents entering the reservoir (Ford, 1990). These can greatly alter the existing DO regimen, depending upon their direction of flow and the level at which they move through the reservoir (Cole and Hannon, 1990). Because the inflow density usually differs from the density of the reservoir water surface, inflows enter and move through reservoirs as density currents. Density differences can be caused by temperature, total dissolved solids, and suspended solids (Ford, 1990). Depending upon the density difference between the inflow and reservoir, these currents carrying nutrient and sediment loads can enter the epilimnion, metalimnion, or hypolimnion as overflow, interflow, or underflow *(Figure 2.3)* (Ford, 1990). The inflowing loads alter the existing regimen (turbidity, DO, nutrient loading,...) of the strata they enter. Moreover, organic matter loads coming into a reservoir with inflow do not immediately settle in the sedimentation zone, but, due to its small size and weight, travel down-reservoir to the end of the main sedimentation zone. This organic matter has considerable DO demand, and where it is deposited is usually the area where the anoxic zone first develops in a reservoir (Cole and Hannon, 1990).

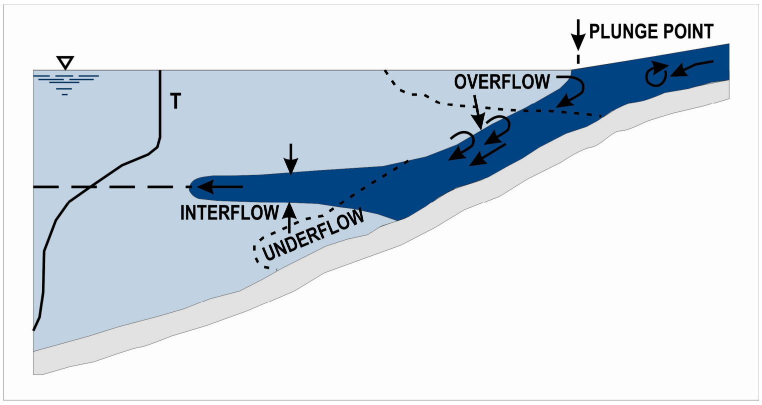


*Figure 2.3: Density inflows to impoundments (Ford, 1990: 31)*

Outlet location is also important in determining the DO distribution within a reservoir. Bottom-release reservoirs usually have a substantially greater portion of hypolimnetic water with DO values above 4 $mgl^{-1}$ than reservoirs with surface-level outlets; because reservoirs with surface withdrawal increase the residence time of the hypolimnetic waters, which allows oxidative processes to cause greater deoxygenation in the hypolimnion (Cole and Hannon, 1990). Dissolved nutrients are also released in the outflow from bottom-release reservoirs, which can result in a decrease in nutrients and subsequent decrease in primary production, thereby reducing the oxygen demand in the lacustrine zone (Cole and Hannon, 1990).

### *2.6.3 Photosynthesis and respiration*

Phytoplankton has been shown to be a major contributor of DO to reservoirs. Although important, the contribution of aquatic macrophytes and periphyton to the DO budget in reservoirs has yet to be determined (Cole and Hannon, 1990). Photosynthesis is generally responsible for the commonly observed oxygen pulse in the epilimnion of reservoirs (Cole and Hannon, 1990). A diel pulse generally increases from a down or post dawn low activity to high activity in the late afternoon and then steadily decreases throughout the night due to continuing demands of community respiration (Cole and Hannon, 1990; Thornton et al., 1998). A diel DO pulse is more common in the riverine zone than in the lacustrine zone of a reservoir, except in large coves in lacustrine zone, where littoral zone plants and phytoplankton blooms are often abundant (Cole and Hannon, 1990).

### *2.6.4 Wind*

Like in natural lakes the primary effect of wind on the DO distribution in reservoirs is through wind-induced mixing, which moves water in the lower layers to the surface (Cole and Hannon, 1990; Wetzel, 2001). The wind causes a gain in oxygen through the air-water interface by helping to maintain the partial pressure differential necessary to sustain oxygen diffusion into the water, or a loss of oxygen by bringing supersaturated waters to the surface, where oxygen is lost to the atmosphere (Cole and Hannon, 1990; Wetzel, 2001). In either case wind mixing aids in maintaining relatively uniform oxygen concentrations in the epilimnion during stratification and throughout the entire water column during and after overturn (Cole and Hannon, 1990).

## 2.7 Reservoir nutrient dynamics

### *2.7.1 External loading*

Reservoir water quality and productivity are controlled to a large extent by the quantity and quality of external nutrient loadings. As mentioned in previous chapters the nature of these nutrient inputs reflect, in turn, climatic regime and various watershed or drainage basin characteristics, including morphology, soil type, and land use. Rock weathering within the watershed and sea spray still dominate the major ion composition of the world's fresh waters (Robards et al., 1994). Farming and settlement probably have the greatest impact on nutrient concentrations, and industry and atmospheric pollutants influence those of trace elements (Robards et al., 1994). The fate of these elements when they enter a water body is sedimentation, incorporation into the biomass, litter or soil, or loss to the stream in a dissolved or suspended state. Sedimentation and subsequent sediment-water interactions are major regulatory processes influencing the nutrient status of lakes and reservoirs (Kennedy and Walker, 1990; Thornton et al., 1998). Sedimentation, like other nutrient-related processes in inflow-dominated reservoirs, shows longitudinal gradients, with the highest sedimentation rates generally occurring in the portion of the nearest inflow, in the riverine zone (Kennedy and Walker, 1990; Thornton 1990b). Inflow loads, a large percentage of which are often associated with suspended particulates, progress through the riverine zone and then decline along the longitudinal gradient within a reservoir, as a result initially from the reduced carrying capacity for suspended particulates, but later and further downlake because of phytoplankton uptake and setting (Kennedy and Walker, 1990). Therefore, phytoplankton production may be low in the headwaters due to inorganic turbidity and flushing, but often increases downlake (Kennedy and Walker, 1990). Nutrient utilization by phytoplankton is potentially greatest near the boundary between the transition and riverine zone, and is further diminished in the lacustrine zone where, similarly to natural lakes, vertical gradients resulting from thermal stratification may provide important nutrient supplies for phytoplankton growth (Kennedy and Walker, 1990).

### *2.7.2 Internal loading*

Seasonal releases of nutrients from storage sites within a lake or reservoir (e.g., from the sediments) can have a pronounced impact on their status in the lake, particularly during periods when inputs from external sources are minimal, i.e. in dry periods (Kennedy and Walker, 1990; Wetzel, 2001). In highly productive stratified reservoir inputs of both allochthonous and autochthonous organic matter can result in a completely anoxic hypolimnion and consequent increases in nutrient releases (Cole and Hannon, 1990; Kennedy and Walker, 1990). In unproductive reservoirs low allochthonous organic inputs and low autochthonous production may lead to anoxic conditions of only limited extent (Kennedy and Walker, 1990).

## 2.8 Land-Water interface

Reservoir inflows are rather channelized and often not intercepted by energy-dispersive and biologically active wetlands and littoral interface regions (Wetzel, 2001). Due to water fluctuations induced by reservoir operation, large areas are alternately inundated and exposed; these manipulations usually prevent the establishment of productive, stabilizing wetland and littoral flora within the reservoir water body area (Ford, 1990). The reduction or elimination of wetland and littoral communities around many reservoirs minimizes the extensive nutrient and physical retention capacities that function effectively in most natural lake ecosystems (Wetzel, 1990b).

## 2.9 Eutrophication

Although many definitions of lake eutrophication exist, based on array of conditions associated with increased productivity, the consensus among limnologists is that the term eutrophication is synonymous with increased growth of the biota of lakes and that the rate of increasing productivity is accelerated over that rate that would have occurred in the absence of perturbations to the system (Wetzel, 2001; Hupfer and Hilt, 2008). Reservoirs, like natural lakes, are affected by the process of eutrophication. Lakes and reservoirs are susceptible to anthropogenic eutrophication or 'an increased rate of ageing' caused by human settlement and activities in the watershed (Thornton et al., 1998). Those lakes and reservoirs tend to show the symptoms of eutrophication (algal blooms, reduction in depth, excessive plant growth, etc.) much more rapidly than reservoirs and lakes not affected by eutrophication (Thornton et al., 1998). Under mainly surface water conditions, the most important nutrient limiting factor causing the shift from a lesser to a more productive state is the availability of phosphorous and nitrogen (Robards et al., 1994; Thornton et al., 1998; Wetzel, 2001).

### *2.9.1 Nitrogen in surface waters*

Nitrogen levels in aquatic systems, as with phosphorous, are inherently linked with excessive algal growth. Total nitrogen levels in waters can vary from as low as 0.1 $mgl^{-1}$ to in excess of 10-20 $mgl^{-1}$ in heavily polluted surface waters (Robarts et al., 1994).

Sources of nitrogen include:

- precipitation falling directly onto the lake surface,
- the decomposition of organic matter,
- nitrogen fixation both in the water and sediments, and
- inputs from surface and groundwater drainage (Wetzel, 2001).

The forms of nitrogen of greatest interest in waters are nitrate ($NO_3^-$), nitrite ($NO_2^-$), ammonium ($NH_4^+$) and organic nitrogen, but nitrate is usually the most important in waters regarding nutrient loads (Robarts et al., 1994). Inorganic and organic forms of nitrogen are all interconvertible with each other by complex processes of fixation, nitrification, and denitrification (Robarts et al., 1994; Chapman and Kimstach, 1998; Wetzel, 2001).

Apart from the natural input of nitrogen from rainfall, the main inputs of nitrogenous matter into freshwater come from farm slurry and sewage and, most significantly, from leaching of fertilizer from agricultural land via point discharges or diffuse runoff. Over the last few decades nitrate levels have increased steadily in many freshwaters predominantly due to increasingly intensive agricultural practices (Robarts et al., 1994; Chapman and Kimstach, 1998). On average only 50 % of available nitrate in the soil is utilised by the crops; most of the particles in the soil are negatively charged so that nitrate is not adsorbed and is carried by rainfall and soil solution into underground aquifers and drainage water (Robarts et al., 1994). The nitrogen cycle in the soil is extremely complex and the amount of nitrate leached depends on many factors, including the crop, chemical and physical conditions of the soil, soil moisture and rainfall (Robarts et al., 1994). Moderate environmental disturbances such as floods usually result in increased nitrate in streams, while more severe land disturbance, which accelerates erosion, mobilizes nitrate in solution and large quantities of phosphate bound to sediment particles (Robarts et al., 1994); both are then rather leached to surface waters and down-stream to the recipient water body.

### *2.9.2 Phosphorous in surface waters*

Nitrogen may be a limiting nutrient in some situations but phosphorous is generally regarded as the limiting nutrient for primary production (Thornton et al., 1998; Wetzel, 2001). In contrast to numerous forms of nitrogen in lake systems, the most significant form of inorganic phosphorous is orthophosphate ($PO_4^{3-}$) (Wetzel, 2001). Excessive loading of phosphorous in its various physical and chemical forms is known to be a causal factor in the eutrophication of both lotic and lentic waters (Robards et al., 1994; Thornton et al., 1998; Wetzel, 2001; Pepper et al., 2006). Phosphorous occurs in waters in various concentrations, in dissolved or particulate forms and, as inorganically or organically bound species. Total phosphorus concentrations in waters can vary from less than 0.01 $mgl^{-1}$ in small mountain streams to over 1 $mgl^{-1}$ in heavily polluted rivers (Robards et al., 1994). The total phosphorous load of surface water may arise from many sources; these include phosphorous from:

- the leaching and weathering of igneous and sedimentary rocks,
- the decomposition of organic matter,
- effluents of domestic or industrial origin,
- diffuse inputs from agricultural land due to inorganic fertilizer use and organic manure application,
- atmospheric deposition and soil/river bank erosion during storm events.

The entry of phosphorous into a river may be classified as point sources, surface runoff, subsurface runoff, and groundwater runoff. Point source inputs such as sewage treatment plants are of greater significance during periods of low flow and dry years, in wetter years and during storm events, diffuse inputs are the dominant nutrient source (Robarts et al., 1994). The growing utilization of synthetic detergents and phosphate fertilizers has resulted in increased concentrations of inorganic phosphorous in aquatic systems; similarly, the increasing presence of the organic phosphorous is largely due to anthropogenic sources such as domestic sewage, plant, animal wastes and industrial effluents (Robarts et al., 1994; Chapman and Kimstach, 1998).

# 3 DESCRIPTION OF THE STUDY AREA

## 3.1 Geographic and geological characteristics

The Vogrščcek reservoir is situated in western Slovenia in lower Vipava valley. The Vipava valley expands in east–west direction between two carbonate plateaus; steep cliffs of the Trnovski gozd plateau rise at the north of the valley and the Karst plateau on its southern margin *(Figure 3.1)*. The two plateaus arose during tectonic mountain-forming processes in Tertiary and were overthrusted over Eocene fysch layers (Luznik and Vrhovšek, 1992). The valley is named after the Vipava River which represents the main watercourse of the valley and one of the major factors that contributed to today's morphology of the valley.

The reservoir was built on the Vogrščcek stream, a right tributary of the Vipava River; precisely the Vogrščcek stream is a left tributary of the Lijak stream, which is a right tributary of the Vipava River *(Figure 3.1)*. The reservoir barrier is situated 3.7 km upstream from the confluence of Vogrščcek and Lijak. The Vogrščcek stream originates above the village named Osek in the periglacial slope gravels deposited at the base of the Trnovski gozd plateau and it has characteristics of a torrent. The stream basin expands parallel to Vipava valley, for about 6 km in length and is about 1.5 km wide (Bratina et al., 1983). After passing the Osek village the stream reaches the Črniče field (in Slovenian: Črniško polje) where it turns towards south-west and continues its way within 200 to 300 m wide valley, where in the 80-ties the Vogrščcek reservoir was built *(Figure 3.1)*

*Figure 3.1: The location of the Vogrščcek reservoir (from Kranjc et al., 1999: 10, elaborated by M. Kunst)*

Geologically, the reservoir drainage area consists of Eocene flysch layers, which are composed of marlstone, sandstone and lime-sandstone (Trček, 2005). The bottom of Vogršček stream valley is covered with Quaternary alluvial deposit partially mixed with flysch deluvium at the lowest part of the slopes. The alluvial deposit predominantly consists of clay-sandstone soil layers along with pebbles and blocks of sandstone and limestone, while the delluvial cover is formed of silty-sandy clays and sandy silts mixed with fragments and blocks of marlstone, sandstone, and limestone (Trček, 2005) *(Figure 3.2)*. These rocks and soils, including carbonate rocks that form the Trnovski gozd plateau at north of the drainage basin, are the main source of material and matter transported in different forms (e.g., pebbles, blocks, fragments, suspension, dissolved…) by the Vogrščck stream and its tributaries to the reservoir water body and represent the reservoir sediment loads.

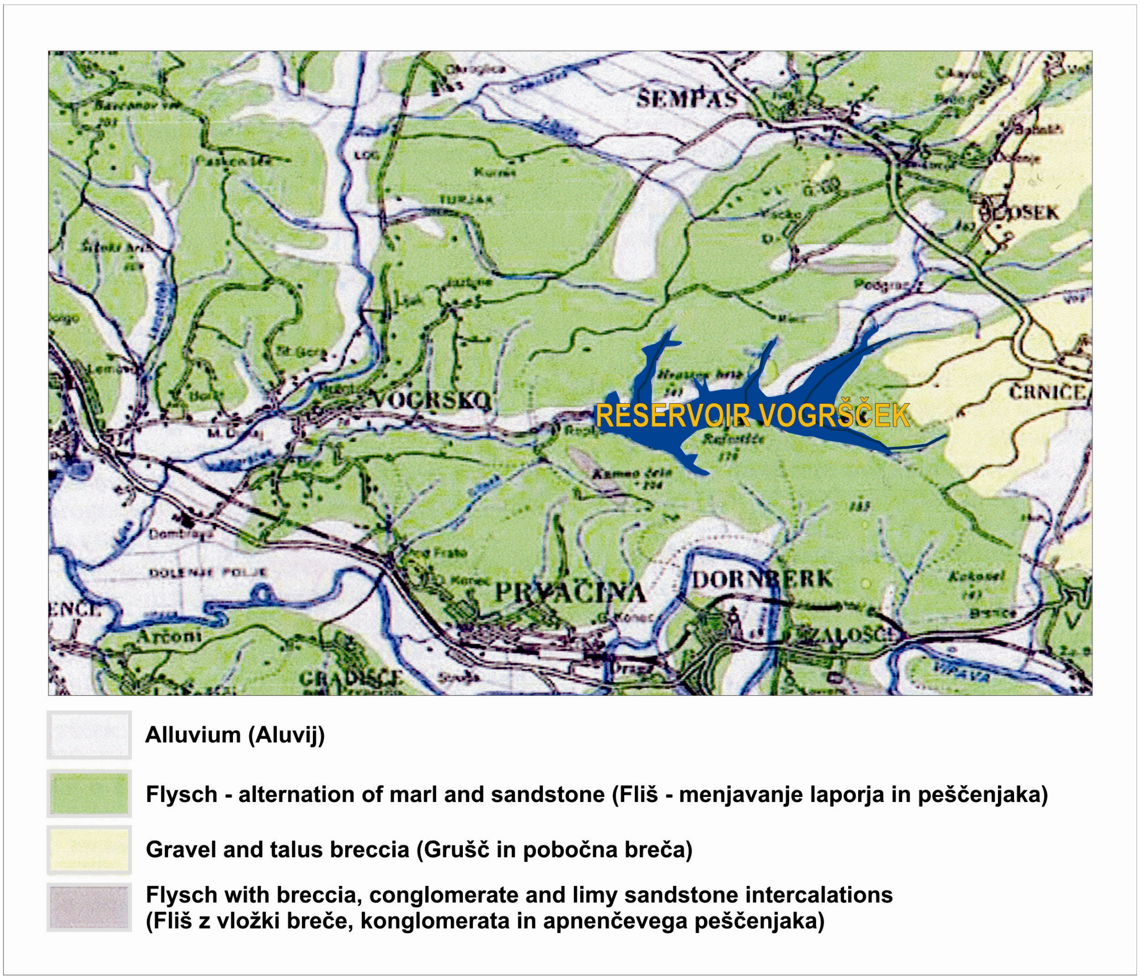


***Figure 3.2: Geological characteristics of the study area (Trček, 2005)***

## 3.2 Climate

The Karst plateau rising on the south fringe of Vipava valley has on average an altitude of 250 m, which allows strong Mediterranean influence from the Adriatic Sea to dominate the region. This dominance is typical for the Sub-Mediterranean climate, characterized by higher average air temperature, about 10.8 $^{o}$C (Luznik and Vrhovšček, 1992). Monthly precipitation in the year 2010 compared to minimums, maximums and average monthly precipitations in the period from 1991-2010 are shown on Figure 3.3 (ARSO, 2011a). The twenty year series (1991-2010) of rainfall for the area shows that average precipitation is 1437 mm *(Figure 3.3)*. The precipitation peaks are typical for autumn and spring, for the periods from March to May and September to November. However, the distribution of the precipitation is very inconvenient considering the fact that sometimes a monthly precipitation amount can be accomplished in one day (Luznik and Vrhovšek, 1992). Due to climate characteristics and low permeability soils the impacts of floods and draughts in Vipava valley can be extreme. These impacts are strengthened by strong winds typical of the region (in Slovenian: burja) which additionally dry up the area, increase evaporation, and reduce soil moisture (Luznik and Vrhovšek, 1992).

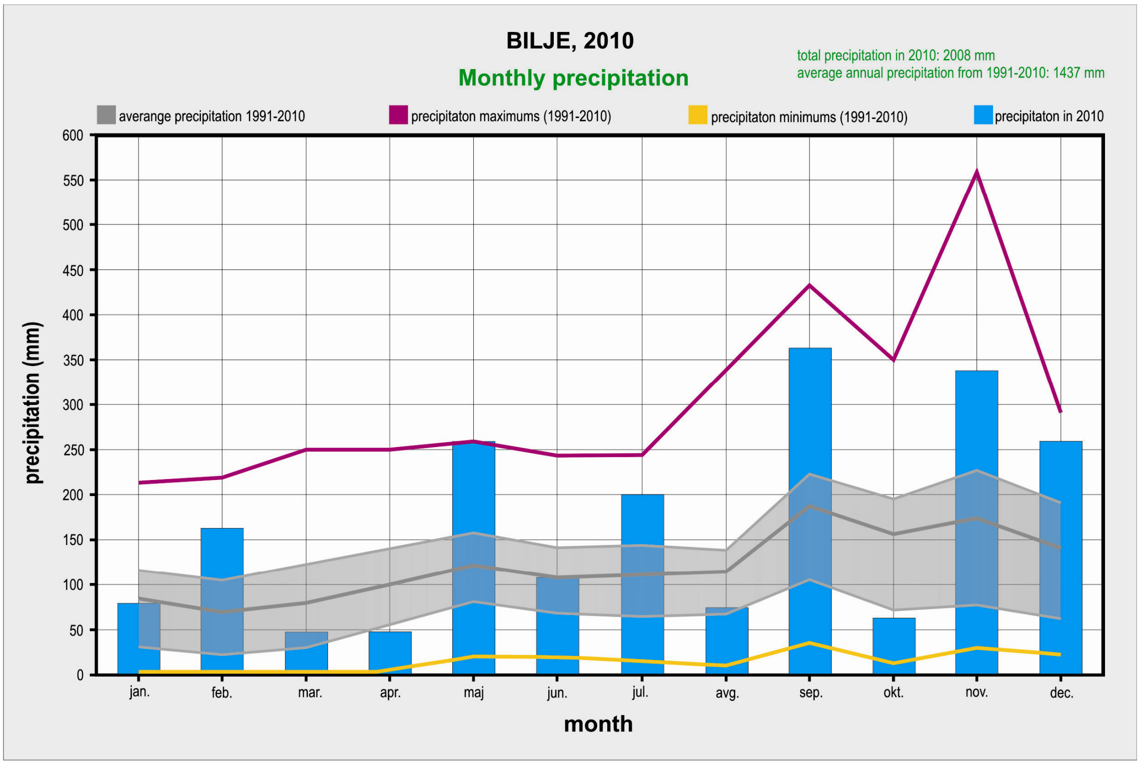


***Figure 3.3: Monthly precipitation at Vogrščček reservoir area in year 2010 compared to monthly precipitations data for the period from 1991 – 2010 (ARSO, 2011a)***

## 3.3 Land use

Despite all mentioned inconveniences, the climate, relief and soil characteristics in Vipava valley are ideal for agricultural land use, which developed and intensified through decades. Hilly terrain at the northern part of the reservoir is used for viticulture, different kinds of crops and fruit cultivation, while the southern part is covered with forest *(Figure 1.1 and Figure 3.1)*. Land owners and farmers are mainly inhabitants of the surrounding rural villages containing up to 100 houses (Osek, Vitovlje), dispersed settlements (Podgrac, Visoko) and some single households, all situated at the north from the reservoir *(Figure 3.1 and Figure 3.2)*.

## 3.4 Vogršček reservoir

### *3.4.1 Purpose and build up*

The Vogršček reservoir was established in years 1986 – 1988 by building a barrier on the Vogršček stream and flooding a part of the valley along the Vogršček stream. The flooded area was not populated. Before the reservoir was built, part of the area was used for meadows the rest was overgrown by vegetation and forest. Before the build up the flora and fauna of the area were very well documented (Dokumentacija …,1983). The vegetation was not removed before flooding.

The reservoir was built for two main purposes. The first is irrigation of the cca. 5000 ha of cultivated areas situated in the lower part of the Vipava valley and the second is controlling the flood wave (Bratina et al., 1981). Beside irrigation and flood control the reservoir serves also for keeping the water levels of the Lijak stream and the Vipava river higher during dry periods (Batič, 2008).

Before the barrier was completed and the reservoir was put up, a highway (HC Nova Gorica - Vipava) dam was built within the reservoir area, which divides the actual reservoir water body in two parts - the smaller North-Eastern upper basin and the bigger main basin *(Figure 3.4)*. The upper basin is situated northward or behind the highway, while the main basin is situated southward of the highway dam (Batič, 2008). The upper basin serves as a recipient of the Vogršček stream and other inflows originating from the surrounding rural area. There is no documented data that the water from the upper basin was ever used for irrigation. The upper basin is connected to the main basin with a spillway (overflow facility) *(Figure 3.4)*. The spillway is designed to maintain the water surface below the determined level. When the water level reaches the overflow facility fringe it flows under the dam from the upper to the main part of the reservoir (Batič, 2008; Poslovnik…, 2008). The main basin serves as major water storage for irrigation purposes.

Beside the highway dam, following structures for maintenance and control of the facility are situated within the reservoir area *(Figure 3.4 and Figure 3.5)* (Batič, 2008; Poslovnik…, 2008):

- the barrier,
- the spillway (overflow) facility;
- administrative and control building,
- the withdrawal and pumping facility,
- Črnilče Pump facility– not in use,
- connection road,
- telephone and electricity junction, and
- gas conduit.

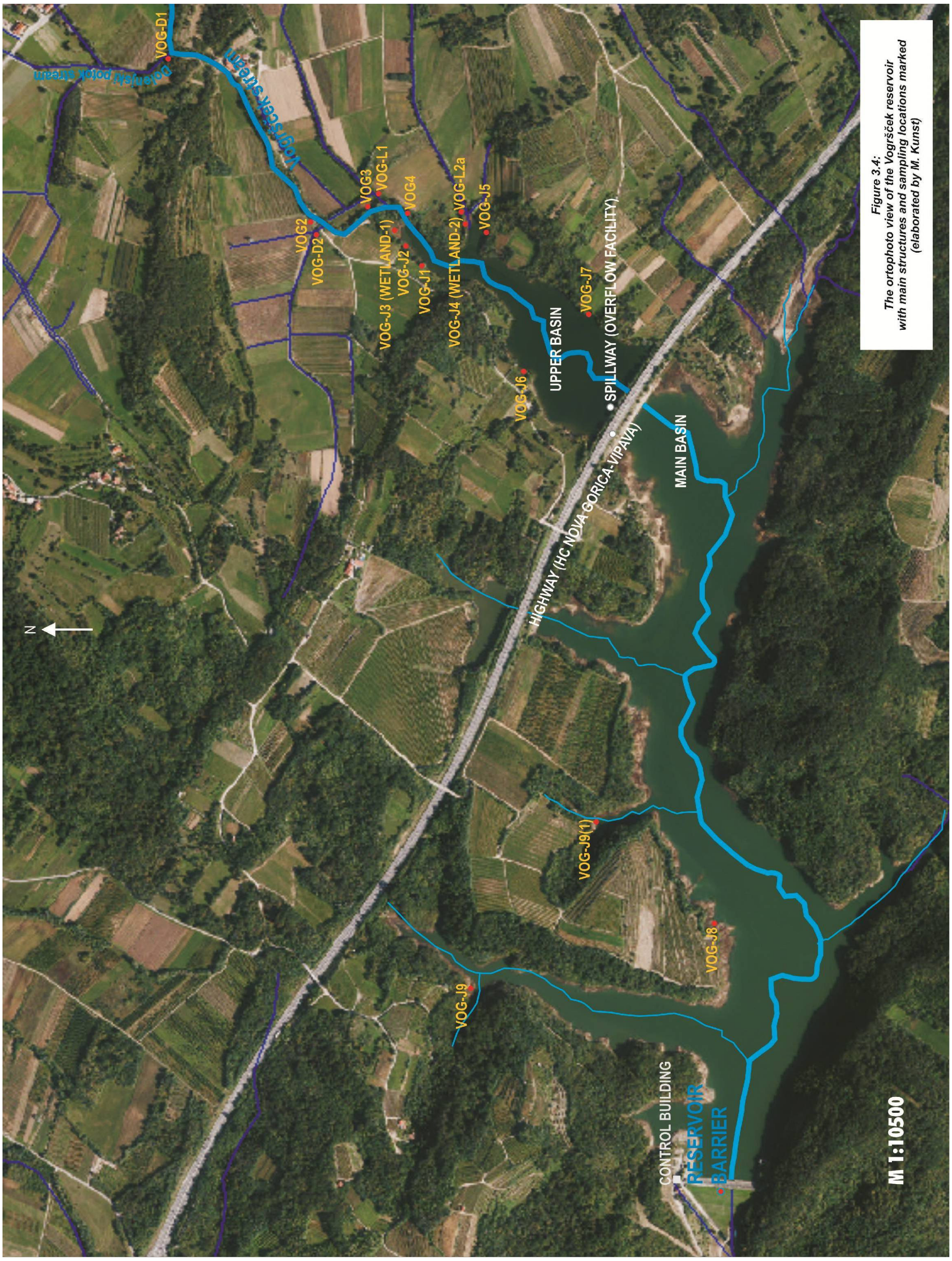


***Figure 3.4: The ortophoto view of the Vogrščček reservoir with main structures and sampling locations marked (elaborated by M. Kunst)***

***Figure 3.5: The ortophoto view of the Vogršček reservoir – upper basin detail, with main structures and sampling locations marked (elaborated by M. Kunst)***

### 3.4.2 *Hydrological and technical data*

The drainage area of the Vogrščček reservoir is 11.25 km$^2$. The total volume of the accumulation is 8.5 mio m$^3$ but, the actual useful volume is 8.05 mio m$^3$. 84.5 % of the useful volume (about 6.8 mio m$^3$ of water) is intended for irrigation. At the main basin it represents the volume from level 98.80 m a.s.l. to 80.00 m a.s.l., at the upper basin this volume ranges from the maximal upper basin level 102.50 m a.s.l. to 99.30 m a.s.l., which is the level of constant inundation. There is no documented data that the water from the upper basin was ever used for irrigation, and also the Črniče Pump facility, which is situated at the upper basin, is in badly-kept state *(Figure 3.5)*. The remaining 1.25 mio m$^3$ (15.5 %) is intended for controlling the flood wave (Batič, 2008; Poslovnik…, 2008).

The barrier was made by building a dam of soil and big rocks. The sealing part consists of clay and silty materials with a two-layer filter placed on both sides. About 250.000 m$^3$ of material was used to build the barrier. (Batič, 2008; Poslovnik…, 2008). Two steel barrels surrounded by concrete were placed in the barrier bottom, under the minimal water level; one to assure the ecologically acceptable flow (EAF) of the Vogrščček stream through the floor let-out and for quick withdrawal in case of emergency, and the other for regular withdrawal and for irrigation withdrawal *(Figure 3.6)*. The established ecologically acceptable flow (EAF) of the Vogrščček stream downstream is 15 ls$^{-1}$ (Batič, 2008; Poslovnik…, 2008).

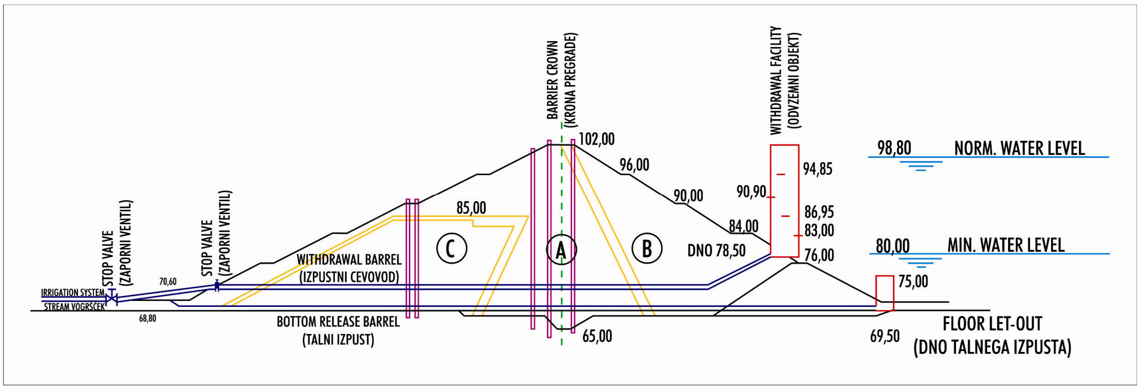


***Figure 3.6: Vogrščček reservoir barrier plan (Stibilj, 2001/2002)***

<u>Main basin characteristics</u>

| | |
|---|---|
| The total surface area: | 90 ha |
| Shore line: | 11 000 m |
| Maximal operational fluctuation: | 20.5 m. |
| Accumulation volume at normal water level: | 6.8 mio m$^3$ |
| Water level (depth) at the barrier: | 26 m |
| Barrier height: | 35.40 m |
| Barrier length: | 174 m |

Upper basin characteristics

| | |
|---|---|
| The total surface area: | 9 ha |
| Shore line: | 1.900 m |
| Maximal operational fluctuation: | 3.2 m |
| Accumulation volume at normal water level: | 0.26 mio $m^3$ |
| Water level (depth) at the highway dam: | 9 m |
| Highway dam height: | 18 m |
| Highway dam length: | 174 m |

### *3.4.3 Maintenance and control*

The Vogrščstill reservoir is a facility of water infrastructure in property of the Republic of Slovenia. The Ministry of Environment and Spatial Planning (Environmental Agency of the Republic of Slovenia, Office for water management) (abb. MOP, ARSO) together with the Kmetijstvo Vipava d.d. (Agriculture Vipava joint-stock company), under the competence of the Ministry of Agriculture Forestry and Food, direct the managing of the reservoir in the name of the owner. The operator of the facility is Hidrotehnik d.d. (abb. operator), which is the performer of obligatory state economical public service for water regulation in Soča river basin. The operator is responsible for operation, maintenance and surveillance of the facility and for reporting about its condition (Batič, 2008; Poslovnik…, 2008).

## 3.5 Locations of sampling

Two streams represent the major inflows to the reservoir upper basin: the Vogršček stream and Dolenjski potok stream; however, several minor melioration ditches gravitate towards the reservoir from the surrounding agricultural area *(Figure 3.4)*. These ditches are possible recipients of the cultivated land run-offs. At the north-eastern margin of the upper basin two wetlands have formed naturally; one in the embayment aside of the Vogršček stream inflow, and one within the second embayment where the Črniče Pump facility is situated *(Figure 3.5)*. According to Vrhovšek and Vovk Korže (2009) the wetlands function as mitigation zone and buffer the inflowing loads after they have entered the upper basin.

Sampling locations were selected based on the purpose of the study, which was (i) to determine a possible impact of human activities within the reservoir drainage basin on measured water quality variables of the upper basin and its inflows, and (ii) to determine a possible impact of the two wetlands at the upper basin. Altogether sixteen sampling locations were chosen *(Figure 3.4)*:

- three at Vogršček stream, marked: VOG2, VOG3 and VOG4,
- one at Vogršček stream tributary Dolenjski potok, marked: VOG-D1,
- three at tributary melioration ditches, marked: VOG-D2, VOG-L1 and VOG-L2a,
- three within the wetland-1 and wetland-2, marked: VOG-J2, VOG-J3, and VOG-J4,
- four at the upper basin, marked: VOG-J1, VOG-J5, VOG-J6, and VOG-J7, and

- two at the main basin for the purpose of comparison samples, marked: VOG-J8, and VOG-J9. For the first sampling the VOG-J9 location chosen was another – the one marked VOG-J9(1) on the Figure 3.4. We changed the location after the first sampling because the actual VOG-J9 location was easier to access and it turned out to be more representative for our study.

VOG2 - Vogrščec stream
GKY: 5403631
GKX: 5086298
Description: the sampling site is located in the immediate vicinity of cultivated crops, just upstream from the bridge on the country road crossing the Vogrščec stream *(Figure 3.4 and Figure 3.7)*. The channel is 2.6 m wide and the water is running. The channel bed is pebbly and stony and overgrown with mosses, diatoms and green algae. The lower part of the stream banks is covered in stone – channelized, the rest is covered with vegetation. The species recorded were: willow tree *(Salix sp.)*, alder *(Alnus glutinosa)*, blackberry *(Rubus sp.)*, black locust *(Robinia pseudoacacia)*, reed canarygrass *(Phalaris arundinacea)*.

**Figure 3.7: VOG2 sampling location**

**Figure 3.8: VOG3 sampling location**

VOG3 - Vogrščec stream
GKY: 5403682
GKX: 5086171
Description: the sampling site is located about 150 m downstream from the bridge on the country road crossing the Vogrščec stream *(Figure 3.4 and Figure 3.8)*. The channel is 3.3 wide m with running water. The channel bed is pebbly and stony and overgrown with diatoms and green algae, mosses are rare. The left stream bank is partly covered in stone – channelized. The location is shadowy and forested. Among the vegetation alder *(Alnus glutinosa)* prevails.

VOG4 - Vogrščček stream

GKY: 5403636

GKX: 5086094

Description: the sampling site is located at the Vogrščček stream inflow into the upper basin *(Figure 3.4 and Figure 3.9)*. The channel is 7.1 m wide with stagnant water. The channel bed consists of mud. The site is shadowy and located within an alder wet forest. Beside alder *(Alnus glutinosa)*, also hedge maple *(Acer campestre)*, blackthorn *(Prunus spinosa)*, willow tree *(Salix sp.)*, spindle tree *(Euonymus europaeus)*, cornel *(Cornus mas)*, and reed canarygrass *(Phalaris arundinacea)*, were recorded. Cultivated crops are located just above the forest belt.

***Figure 3.9: VOG4 sampling location***

***Figure 3.10: VOG-D1 sampling location***

VOG-D1 – Dolenjski potok, Vogrščček stream right tributary

GKY: 5403992

GKX: 5086610

Description: the sampling site is located at Dolenjski potok, Vogrščček stream right tributary, about 5 m upstream from the junction of both streams *(Figure 3.4 and Figure 3.10)*. Dolenjski potok collects water from the tributaries under the village Osek, and few other single households, and from surrounding crops and vineyards. The channel is 2 m wide with running water. The channel bed is pebbly and stony and overgrown mostly with diatoms. The stream banks are covered in stone – channelized. The surrounding vegetation consists of alder *(Alnus glutinosa)*. Vineyards are located in the immediate vicinity.

VOG-D2 – melioration ditch, Vogrščček stream right tributary

GKY: 5403604

GKX: 5086291

Description: the sampling site is located at Vogrščček stream right tributary; about 13 m upstream from the bridge crossing the Vogrščček stream on the country road *(Figure 3.4 and Figure 3.11)*. VOG-D2 is a melioration ditch which collects water from surrounding cultivated crops and vineyards. The channel is 1.3 m wide. The water is stagnant, but on two occasions after precipitation in spring and autumn the water was running slowly. During the summer draught the ditch was dry. The channel bed consists of mud. The banks and the channel bed are covered by vegetation: lakeshore bulrush *(Schoenoplectus lacustris)*, cattail *(Typha latifolia)*, horsetail *(Equisetum sp.)*, and reed canarygrass *(Phalaris arundinacea)*.

***Figure 3.11: VOG-D2 sampling location***

***Figure 3.12: VOG-L1 sampling location***

VOG-L1 – melioration ditch, Vogrščček stream left tributary

GKY: 5403682

GKX: 5086163

Description: the sampling site is located at Vogrščček stream left tributary, about 40 m upstream from the Vogrščček stream inflow into the upper basin *(Figure 3.4 and Figure 3.12)*. VOG-L1 is a melioration ditch which collects water from surrounding crops and vineyards. The channel is 1.85 m wide with stagnant water. The channel bed consists of mud. During the summer draught the ditch was dry. The site is shadowy and located within an alder wet forest. Beside alder *(Alnus glutinosa)*, hedge maple *(Acer campestre)* was recorded.

VOG-L2a – melioration ditch, second upper basin inflow

GKY: 5403663

GKX: 5085963

Description: the sampling site is located at a melioration ditch about 10 m upstream before its inflow into the upper basin *(Figure 3.4 and Figure 3.13)*. The ditch collects water from surrounding crops and vineyards. The channel is 1.55 m wide. The channel bed consists of mud and the water is stagnant. The location is shadowy and forested. Species alder *(Alnus glutinosa*), willow tree *(Salix sp.)* and reed canarygrass *(Phalaris arundinacea)* were recorded.

**Figure 3.13: VOG-L2a sampling location**

**Figure 3.14: VOG-J1 sampling location**

VOG-J1 – upper basin

GKY: 5403532

GKX: 5086057

Description: the sampling site is located at the right bank of the basin downstream from the wetland-1 *(Figure 3.4 and Figure 3.14)*. The bank is covered with grass and is a popular fishermen spot. The samples were taken from the epilimnium next to the bank. The bottom consists of mud. The species recorded at the site were: lakeshore bulrush *(Schoenoplectus lacustris)*, cattail *(Typha latifolia)*, common reed *(Phragmites australis)*, reed canarygrass *(Phalaris arundinacea)*, yellow water flag *(Iris palustris)*, and small nettle *(Urtica urens)*.

VOG-J2 – upper basin, at the outer edge of the wetland-1

GKY: 5403584

GKX: 5086109

Description: the sampling site is located at the right bank of the basin within a basin embayment and at the outer edge of the wetland-1 *(Figure 3.4 and Figure 3.15)*. The samples were taken from the epilimnium next to the bank. The bottom consists of mud. The location is shadowy and overgrown by vegetation. The species recorded at the site were: lakeshore bulrush *(Schoenoplectus lacustris)*, cattail *(Typha latifolia)*, common reed *(Phragmites australis)*, reed canarygrass *(Phalaris arundinacea)*, alder *(Alnus glutinosa)*, and willow tree *(Salix sp.)*.

**Figure 3.15: VOG-J2 sampling location**

**Figure 3.16: VOG-J3 sampling location**

VOG-J3 – upper basin, within the wetland-1

GKY: 5403618

GKX: 5086131

Description: the sampling site is located within a basin embayment *(Figure 3.4 and Figure 3.16)*. The samples were taken from the shallow water within the wetland-1. The sediment consists of mud and clay. The wetland-1 is between 10 to 30 m wide and consists of following emergent plants: cattail *(Typha latifolia)*, common reed *(Phragmites australis)*, water mint *(Mentha aquatica)*, reed canarygrass *(Phalaris arundinacea)*, and horsetail *(Equisetum sp.)*.

VOG-J4 – upper basin, within the wetland-2

Gauss Kruger Y: 5403630

Gauss Kruger X: 5085962

Description: the sampling site is located within a basin embayment *(Figure 3.4 and Figure 3.17)*. The samples were taken from the shallow water within the wetland-2. The bottom consists of mud. The wetland-2 is between 9 to 15 m wide and following emergent plants were recorded: cattail *(Typha latifolia)*, and water mint *(Mentha aquatica)*.

***Figure 3.17: VOG-J4 sampling location***

***Figure 3.18: VOG-J5 sampling location***

VOG-J5 – upper basin

GKY: 5403601

GKX: 5085912

Description: the sampling site is located within a basin embayment at the left bank of the basin and opposite to the wetland-2 *(Figure 3.4 and Figure 3.18)*. The samples were taken from the epilimnium next to the bank. The bottom consists of mud. The site is shadowy and located within an oak - common hornbeam forest. Beside oak *(Quercus sp.)* and common hornbeam *(Carpinus betulus)*, species manna ash *(Fraxinus ornus)* and black locust *(Robinia pseudoacacia)* were recorded.

VOG-J6 – upper basin

GKY: 5403294

GKX: 5085819

Description: the sampling site is located on the right bank of the basin next to a vineyard in the vicinity of the highway that divides the upper basin from the main basin *(Figure 3.4 and Figure 3.19)*. The bank is covered with grass. The samples were taken from the epilimnium next to the bank. The bottom consists of mud. The species recorded at the site were: cattail *(Typha latifolia)*, common reed *(Phragmites australis)*, reed canarygrass *(Phalaris arundinacea)*, horsetail *(Equisetum sp.)*, and small nettle *(Urtica urens)*.

***Figure 3.19: VOG-J6 sampling location***

***Figure 3.20: VOG-J7 sampling location***

VOG-J7 – upper basin

GKY: 5403410

GKX: 5085675

Description: the sampling site is located on the left bank of the basin next to cultivated crops in the vicinity of the highway that divides the upper basin from the main basin *(Figure 3.4 and Figure 3.20)*. The bank is grassy. The samples were taken from the epilimnium next to the bank. The bottom consists of mud. The species recorded at the site were: cattail *(Typha latifolia)*, lakeshore bulrush *(Schoenoplectus lacustris)*, and alder *(Alnus glutinosa)*.

VOG-J8 – main basin

GKY: 5402077

GKX: 5085431

Description: the sampling site is located within a basin cove, at the left bank of the basin next to a wide vineyards area *(Figure 3.4 and Figure 3.21)*. Due to the water level fluctuations part of the bank was without vegetation. At the land-water interface area following species were recorded: cocklebur *(Xanthium italicum)*, devil's beggarticks *(Bidens frondosa)*, redshank *(Polygonum persicaria)*, willow tree *(Salix sp.)*, and cottonwood tree *(Populus sp.)*.

***Figure 3.21: VOG-J8 sampling location***

***Figure 3.22: VOG-J9 sampling location***

<u>VOG-J9 – main basin</u>

GKY: 5401944
GKX: 5085955

Description: the sampling site is located within the biggest embayment at the northern part of the main basin *(Figure 3.4 and Figure 3.22)*. The location is separated from the vineyards area by a forest belt. Part of the bank is bare due to the water level fluctuations. The species recorded at the land-water interface area were: cocklebur *(Xanthium italicum)*, devil's beggarticks *(Bidens frondosa)*, and black locust *(Robinia pseudoacacia)*.

<u>VOG-J9(1) – main basin</u>

GKY: 5402358
GKX: 5085747

The sampling location VOG-J9(1) *(Figure 3.4)* was chosen as VOG-J9 location only for the first sampling. We changed the location after the first sampling, because we found the actual VOG-J9 easier to access and more representative for our study.

# 4 MATERIALS AND METHODS

Field work, sampling and laboratory analyses followed the standard methods adopted for water quality monitoring and assessments and described by: Bartram and Balance (1996), Beim et al. (1998), Chapman and Kimstach (1998), and Thornton et al. (1998).

## 4.1 Field work and sampling

### *4.1.1 Locations and time schedule of sampling*

Sampling locations were selected by studying the reservoir drainage basin characteristics on topographic and ortophoto maps. An accurate field survey was performed to locate the exact points of sampling. These were determined at locations, which were found to be representative for research of the impact of agricultural land use and effluents from settlements on upper basin and its inflows. Based on data collected altogether sixteen sampling locations were selected. To record relative water level fluctuations two marked wooden sticks were placed at the upper basin VOG-J2 and VOG-J4 location. On the first sampling day the actual water level was recorded as zero and during the sampling period levels were recorded in plus or minus centimetres from the relative zero *(Figure 4.1)*.

***Figure 4.1: Relative water level measurement***

The sampling period was from March to November 2010. The time frame was set in relation to seasons considering agricultural activities. Regarding the agricultural land use present in the area (see ch. 3.3), which is mostly viticulture, crops and fruit cultivation, the main agricultural activities are: ploughing, pesticide application, fertilization and manuring. The first sampling was performed before the beginning of agricultural activities on 14th of March 2010 *(Figure 4.2)*. Sampling then proceeded with collecting water samples from April to October, during the months of intensive agricultural activity. The last sampling was done on 20th of November, when the agricultural activity ceased *(Figure 4.2)*. Altogether, ten samplings were performed. On 17th of June sampling was performed *(Figure 4.2)* only at six chosen locations: VOG4, VOG-L2a, VOG-J1, VOG-J2, VOG-J3 and VOG-J4, in order to obtain more data about possible changes in measured variables at the wetlands, the inflow area and the melioration ditch.

Sampling days were chosen based on weather conditions in relation to periods of intensive precipitations and draughts. During the sampling period the highest precipitation occurred in September, with a maximum of 367 mm and in November 342 mm. Precipitation was the lowest in March and April, with a minimum of 47 mm *(Figure 4.1)*. The highest precipitation per day occurred on 31st of May with an amount of 137 mm, followed by a peak on November 8th of 108 mm and a peak of 103 mm on 19th of September.

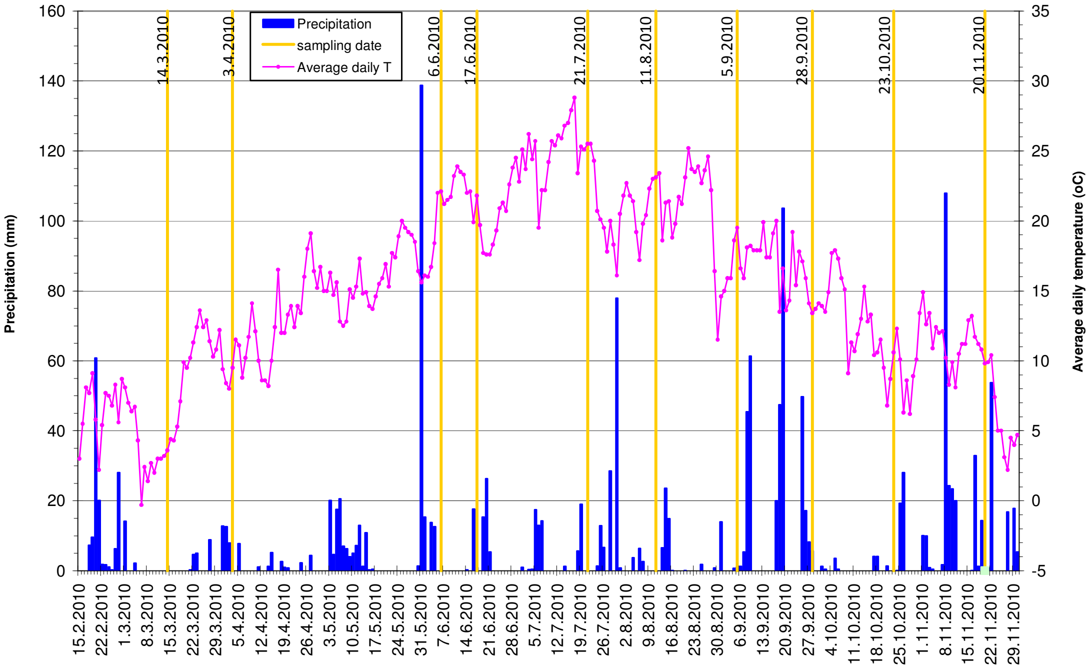


***Figure 4.2: Average daily temperature and precipitation at Vogrščcek reservoir area in sampling period (ARSO, 2011b)***

### 4.1.2 *Sampling*

All the samples obtained were ‘grab sample type’, meaning the samples were taken at the selected location and time by submerging the bottle to a depth of about 10 to 20 cm (Bartram and Balance, 1996). Water samples were taken in 0.5 l plastic bottles and in 50 ml plastic test tubes *(Figure 4.3)*. The samples in the test tubes served to perform ionic chromatography analyses, while the samples in plastic bottles were used for other physical and chemical laboratory analyses performed. In the period of low water level the bottle was submerged to an appropriate depth in order to collect a sample not contaminated by bottom sediment. Any noted specifics at the time of sampling, such as odour and colour were recorded on the sample list *(Appendix 1)*. The vegetation at each sampling location was also documented. All samples were put in a cooler and transported to the designed location. At the location the samples in bottles were held in a refrigerator for the night and tested within 24 hours, while the test tubes were frozen and analyzed within a week. Altogether 148 samples were collected and tested. The respective data are gathered and presented in Appendixes 2.1-2.16.

*Figure 4.3: Sample bottles and test tubes*

*Figure 4.4: Field measurements of T, pH, EC and DO concentration*

### 4.1.3 Field measurements

Measurements of water and air temperature (T), pH, electrical conductivity (EC), dissolved oxygen concentration (DO), and dissolved oxygen saturation were carried out *in situ* simultaneously with sampling. Variables were measured using the WTW (Wissenschaftlich-Technische-Werkstätlen, Weilheim, Germany) MultiLine P4 portable universal pocket-size meter, with pH electrode, SenTix 41 temperature probe, Cell Ox 325 dissolved oxygen probe and TetraCon 325 standard conductivity cell *(Figure 4.4)*. DO measurements were consistent only for the last five samplings, performed from August to November, due to problems with the calibration of the dissolved oxygen probe in spring of 2010.

## 4.2 Physical and chemical laboratory analyses

The samples were analysed at the laboratory of the University of Nova Gorica for the following variables: chemical oxygen demand (COD), biochemical oxygen demand ($BOD_5$), ammonium ($NH_4^+$), total organic carbon (TOC) and toxicity. Measurements of concentrations of cations: calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), potassium ($K^+$), ammonium ($NH_4^+$), sodium ($Na^+$), and anions: fluoride ($F^-$), chloride ($Cl^-$), bromide ($Br^-$), nitrite ($NO_2^-$), nitrate ($NO_3^-$), sulphate ($SO_4^{2-}$), and orthophosphate ($PO_4^{3-}$) were performed at the National Institute of Chemistry in Ljubljana at the laboratory for Environmental science and Engineering by the method of ion chromatography.

### 4.2.1 Chemical oxygen demand (COD)

COD determination was done by method of photometric determination of decrease in chromate concentration after oxidation with potassium dichromate / sulphuric acid / silver sulphate. Nanocolor 500 D photometer (Macherey-Nagel, Germany) was employed. The test is in accordance to the DIN ISO 15705:2003 standard. Standard COD digestion solutions in the range

2 – 40 $mgl^{-1}$ COD, Type 0-27, were used. The chemical oxygen demand of a water sample is determined by silver-catalysed oxidation with potassium dichromate / sulphuric acid at 148 °C during a two hour period. 2 ml of sample was introduced into the digestion solution, shaken, and thermostated at $148^0C$ for 120 min *(Figure 4.5)*. The tubes were then removed from the thermostat, shaken again, left to cool for at least 1 hour, cleaned, and photometrically measured for COD.

***Figure 4.5: COD determination with Nanoclor 500 D photometer***

### 4.2.2 Biochemical oxygen demand ($BOD_5$)

$BOD_5$ was determined by method of photometric determination using Nanocolor 500 D photometer (Macherey-Nagel, Germany). The tube test for determination of the BOD in 5 days in the presence of added nutrients was performed according to the Standard Method DIN 38409-H51. Standard test tubes with reagent $BOD_5$-TTR0 in the range 2 – 3000 $mgl^{-1}$ $O_2$, Test 8-25, were used. The sample was rendered stable at room temperature and pH value corrected to a value between 6 and 8 when necessary. For each set of samples one control-test tube with double ionized water was used as zero value. 20 ml of sample was introduced into the reaction vessel, shaken for 30 s, and after that introduced into the test tube. The incubation of the samples was carried out directly in test tubes for 5 days at $20^0C$ *(Figure 4.6)*. The determination of $BOD_5$ after five days is carried out similarly to the Winkler Method DIN EN 25813-G21 by photometric evaluation of iodine-colour. Two drops of reagent $BOD_5$-TTR1 and $BOD_5$-TTR2, and five drops of reagent $BOD_5$-TTR3 were introduced into test tubes, shaken, and the $BOD_5$ of the sample was measured photometrically *(Figure 4.7)*. The measurements of $BOD_5$ variable were not performed on all the samples each time. The samples were chosen for $BOD_5$ testing based on their COD results; 9-10 samples which had the highest COD levels.

**Figure 4.6: The incubation of the samples for $BOD_5$ determination**

**Figure 4.7: $BOD_5$ determination with Nanoclor 500 D photometer**

### 4.2.3 Ammonium ($NH_4^+$)

For $NH_4^+$ determination two analytical methods were employed: ion chromatography and photometric determination using Nanocolor 500 D photometer (Macherey-Nagel, Germany). Standard tube tests (ISO standardised), Type 0–05, in the range 1 – 40 $mgl^{-1}$ $NH_4$-N, were used. 200 µl of sample was introduced into the test tube, nanofix R2 was added, tube was closed, shaken, and left still for 15 min *(Figure 4.8)*. Photometric determination is done as indophenol. At a pH value of about 12.6 ammonium reacted with hypochlorite and salicylate in the presence of sodium nitroprussiate as catalyst to form a blue indophenol. After 15 min the $NH_4^+$ in the test tube was photometrically measured.

**Figure 4.8: $NH_4^+$ determination with Nanoclor 500 D photometer**

**Figure 4.9: Determination of TOC concentration with Analytic Jena Multi C/N 3100 analyzer**

### 4.2.4 Total organic carbon (TOC)

TOC measurements were done by differential method using the Analytic Jena Multi C/N 3100 analyzer *(Figure 4.9)*. The volume of the sample was 500 µl, and the furnace temperature was $750^0$C. The samples were acidified manually prior to analysing, to values below pH 8. Due to persistent problems with the TOC analytic instrument in spring of 2010, TOC measurements for the first four sets of samples obtained from March to June, and for the last measurement in November were not consistent.

### 4.2.5 Toxicity (luminescent bacteria (Vibrio fisheri) test)

Toxicity was measured with analytic instrument for analysing toxicity with the luminescent bacteria test. The instrumentation used included LUMIStox-300 luminometer, LUMISTherm incubator, and non pathogenic bacteria *Vibrio fischeri* LCK482 (liquid-dried) (Lange, 1999) (DIN/EN/ISO11348-1,-2,-3 standardised) *(Figure 4.10)*. Toxicity determination was done by measuring natural light emission of luminescent bacteria; the inhibition of the light emission in the presence of the sample is determined against a non-toxic control. The pH of the samples was corrected to 6-8 and salt was added (2 % NaCl weight amount) in order to reach the salinity demanded by the test organism. Incubation time of the solutions was 30 min at 15°C. Analyses of toxicity were done twice for all the samples and three or four times for selected samples.

***Figure 4.10: Determination of toxicity with the luminescent bacteria test (Vibrio fisheri) using the LUMIStox-300 luminometer and LUMISTherm incubator***

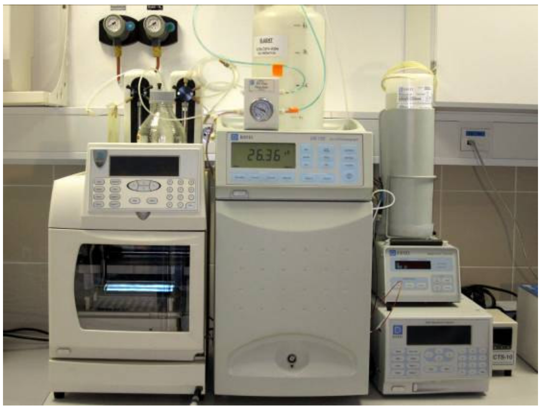


***Figure 4.11: Dionex DX-120***

### 4.2.6 Ion chromatography

Ion chromatography was employed for the measurement of the concentration of following cations: $Ca^{2+}$, $Mg^{2+}$, $K^{+}$, $NH_4^{+}$, $Na^{+}$, and following anions: $F^{-}$, $Cl^{-}$, $Br^{-}$, $NO_2^{-}$, $NO_3^{-}$, $SO_4^{2-}$, $PO_4^{3-}$, in the water sample. Due to limited financial support, cations concentrations measurements were performed only for the last six samplings (from sampling date 21.07.2010 to 20.11.2010), while anions concentrations were measured throughout the sampling period, with the exception of the first sampling (14.3.2010). Dionex DX-120 ICS 3000 analytic instrument was used *(Figure 4.11)*. Anions were separated using AS19 anionic column, the eluent was Sodium hydroxide (NaOH) with concentration changing from 19 to 80 mM. Cations were separated using CS12A cation column, the eluent used was 22 mM Methanesulphonic acid (MSA). The sample was injected into the eluent flow, and pumped into the system. When the sample ions and the eluent ions reach the separation column they bound differently to the covalently bounded exchanging groups in the stationary phase. Motion velocity of a single ion depends on its affinity towards the active position on the ionic exchanger compared to the ions affinity in the eluent towards the same active position. The ions were detected based on electrical conductivity. They were determined qualitatively considering the retention time and quantitatively considering the peak height in comparison to concentrations of standard solutions. Retention time for the anions was 25 min, and for cations was 15 min. The flow was 1mlmin$^{-1}$. Limit of detection (LOD) for ion concentration was 1 mgl$^{-1}$.

## 4.3 Presentation of results and statistics

For the purpose of data and results presentation (Figures of graphs) the variables resulting below the LOD were corrected according to Croghan (2003) by replacing the value below LOD with the LOD/√2.

Linear correlations between water quality variables: EC and major ions, Na and Cl, Ca and Mg, Ca and $SO_4$, TOC and COD, EC and N-$NO_3$, were performed by standard statistic method (Steel, 1996) and shown by plotting one variable against the other.

# 5 RESULTS

## 5.1 Air Temperature

The lowest air temperature 7 °C was recorder in the morning on 14th of March 2010, while the highest air temperature 29 °C was recorded in summer afternoons in June and July 2010 *(Figure 5.1) (Appendix 2.1-2.16)*. Since sample grabbing and measurements took 8 to 9 hours each time, air temperature data changed within a sampling day in accordance to the day time *(Figure 5.1)*. The highest difference within a day air temperature was recorded on 6th of June, when the temperature recorded in the morning at VOG2 was 15,7 °C and at VOG-J9 in the afternoon was 29 °C *(Figure 5.1) (Appendix 2.1-2.16)*.

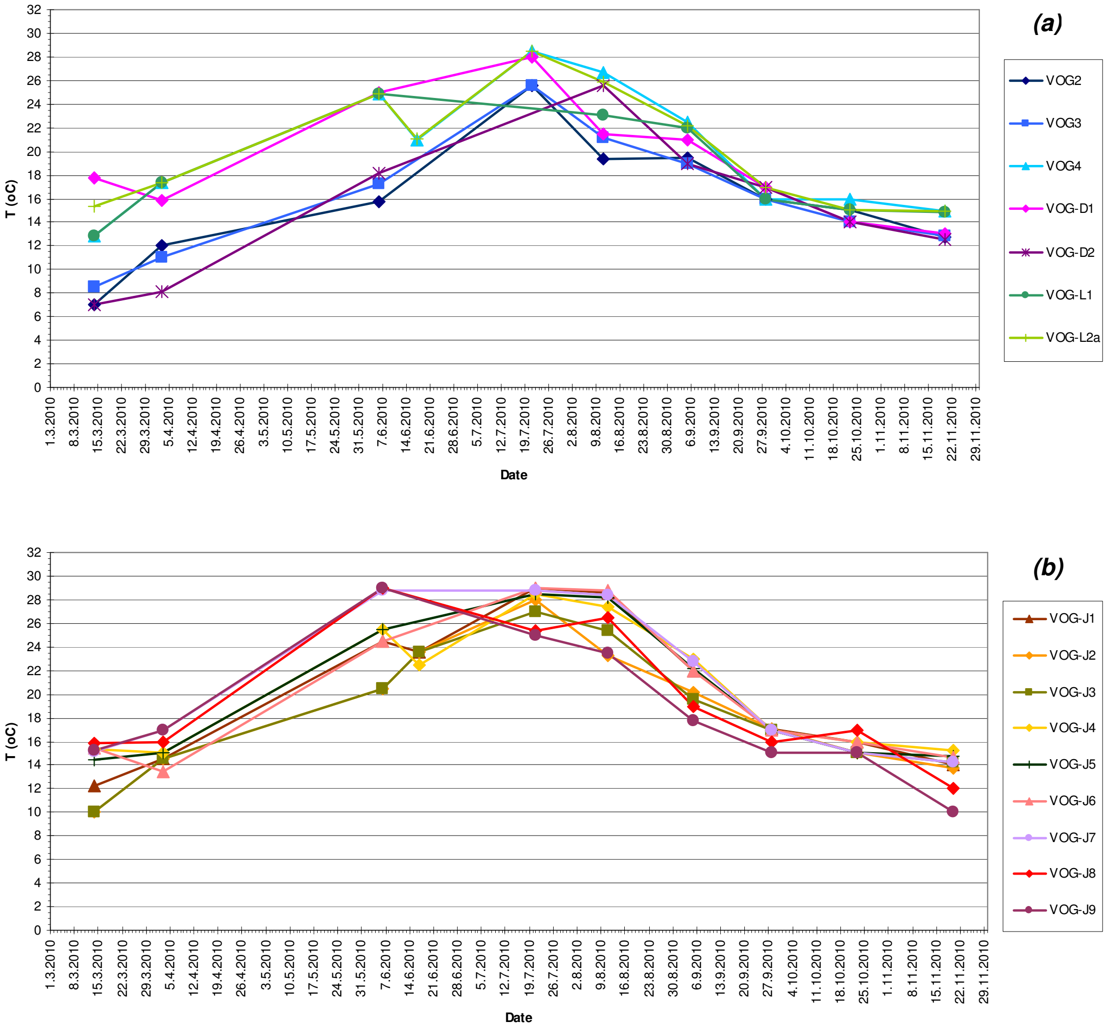
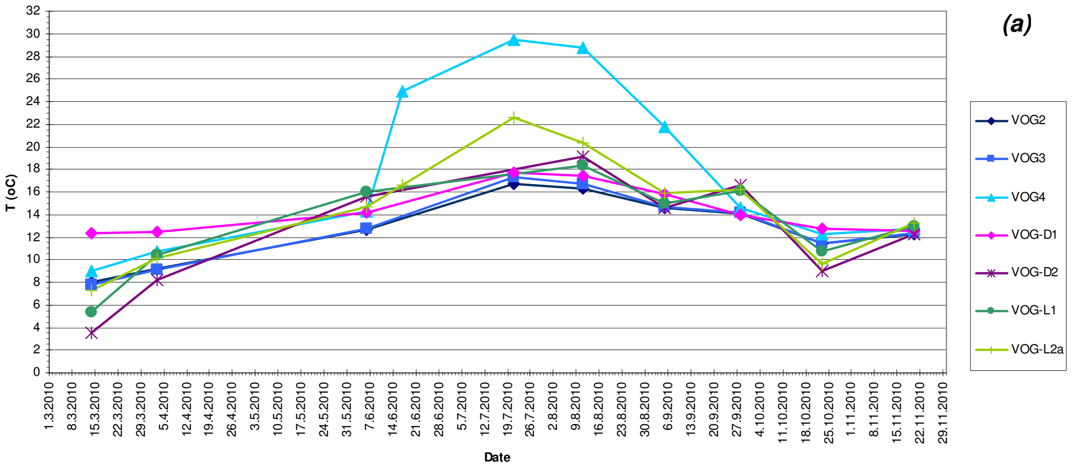


*Figure 5.1: Air temperature at the inflows (a) and at upper and main basin locations (b)*

## 5.2 Water Temperature

Variation in water temperature followed a generally simple pattern over the sampling period at all locations; water temperature had steadily increased in the period from March to July and it remained high until August before it decreased towards autumn *(Figure 5.2)*. The lowest water temperature was recorded in March at all locations, with a minimum of 3.5 °C at melioration ditch VOG-D2. Among the basin locations the lowest temperature recorded was at wetland-1 (VOG-J3), with a minimum of 5 °C *(Appendix 2.1-2.16)*. Noticable difference in water temperature maximum was recorded between basin locations and inflows during the summer, resulting in two distinct data groups. When upper basin reached its maximum of 29.6 °C, the water temperature maximum at the inflows (VOG2, VOG3) did not exceed 17.3 °C. The exception among the inflows was VOG4, with a maximum of 29.5 °C in July. Melioration ditch (VOG-L2a) and wetland-1 (VOG-J3) also showed distinct difference in water temperature with levels that fit in between both groups *(Figure 5.2)*. At the end of September the water temperature levels at the inflows, wetlands, upper and main basin became approximate again, and on 20th of November showed a difference of only 2.1 °C between the maximum (VOG-L2a, 13.3 °C) and the minimum (VOG-J3, 11.2 °C).



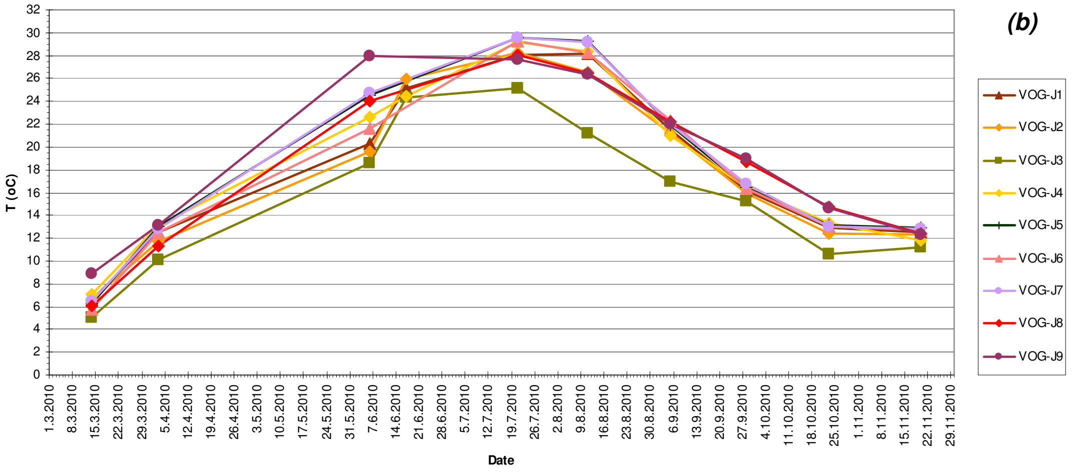


***Figure 5.2: Water temperature at the inflows (a) and at upper and main basin locations (b)***

## 5.3 Water level

During the sampling period the maximal recorded difference between the lowest and the highest relative water level was 5 cm. In summer relative water level was the lowest at both measured locations, VOG-J2 and VOG-J4, with the minimum of – 3 cm *(Appendix 2.1-2.16)*. The relative water level rose above 0 after high precipitation in September and reached the highest level +2 cm on 28th of September.

## 5.4 PH

Average pH values at the inflows varied from 7.6 to 8.2 *(Figure 5.3) (Appendix 2.1-2.16)*. VOG2, VOG3, and VOG-D1 showed an average pH of 8.1, while pH average at melioration ditches VOG-D2, VOG-L1, and VOG-L2a was 7.7. Average pH values at the upper and main basin were 8.2 with a minimum of 7.7 and a maximum of 8.8, with the exception for wetland locations *(Fig. 5.3)*. Wetland locations VOG-J2 and VOG-J4 showed an average pH of 7.8, but pH values at wetland-2 (VOG-J4) varied throughout the sampling period. Meanwhile pH values at wetland-1 (VOG-J3) were overall lower, with a measured minimum of 6.9 in June. In general, recorded pH values were higher at all locations in March and April and tend to decrease towards autumn.

## 5.5 Electrical conductivity (EC)

EC values recorded at inflows are shown in *Figure 5.4*. Based on recorded range two distinct groups can be observed. The first group VOG2, VOG3, VOG-D1, representing Dolenjski potok and Vogršček stream, showed EC values ranging between 328 – 440 µScm$^{-1}$. While EC values at the second group, representing melioration ditches VOG-D2, VOG-L1, and VOG-L2a, varied among measurements, ranging between 317 – 691 µScm$^{-1}$. Inflow VOG4 location again showed a distinct difference from both groups, with a minimum of 262 µScm$^{-1}$ in August, and a maximum of 442 µScm$^{-1}$ in November.

Upper basin EC values did not differ considerably among locations, with the exception of the two wetlands, VOG-J3 and VOG-J4 *(Figure 5.4)*. EC at the upper basin ranged between 251 and 420 µScm$^{-1}$, with the minimum and the maximum recorded respectively in August and November. EC values at wetland-1 (VOG-J3) were consistent with values recorded at the upper basin locations, but showed a jump to 527 µScm$^{-1}$ in September followed by a decrease to EC values coinciding with the upper basin in November. Opposite, wetland-2 (VOG-J4) EC values coincided with the upper basin values until the last measurement in November, when EC at VOG-J4 decreased to 257 µScm$^{-1}$, while all measurements at the reservoir showed an increase in EC values. Main basin EC measurements showed a similar pattern to upper basin values, but the values recorded were in general lower comparing to the upper basin, with a minimum of 217 µScm$^{-1}$ in June and a maximum of 317 µScm$^{-1}$ in March *(Figure 5.4)*.

In general, inflows had higher average EC values compared to both basins values; and within the basins, upper basin EC values were higher than values recorded at the main basin *(Appendix 2.1-2.16)*. EC values recorded at the three melioration ditches were lower in spring and tend to increase towards summer, with the highest peaks recorded in August and October. Opposite, EC values recorded at the upper and main basin were the lowest during summer and tend to increase towards winter *(Figure 5.4)*.

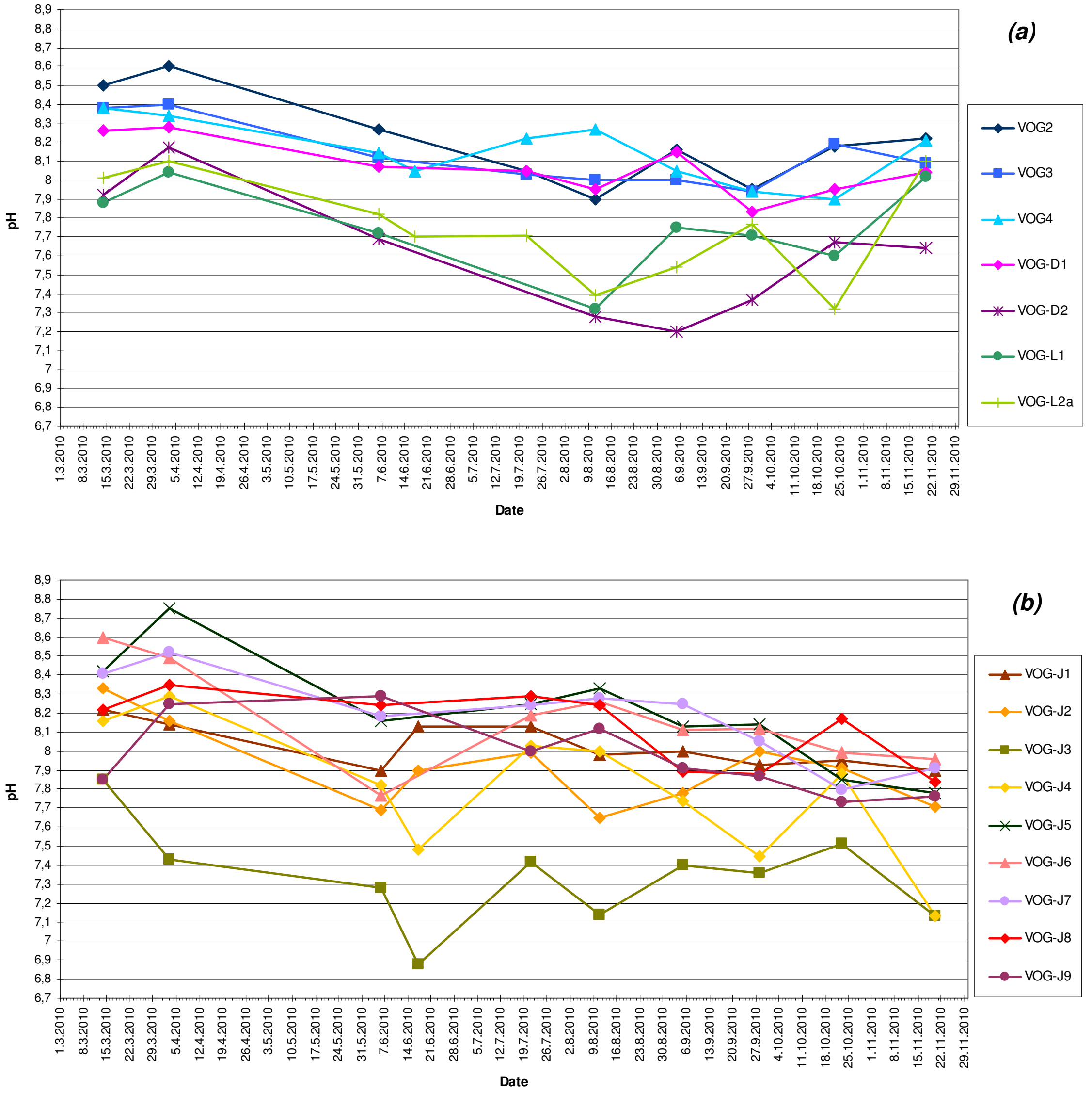


***Figure 5.3: pH at the inflows (a) and at upper and main basin locations (b)***

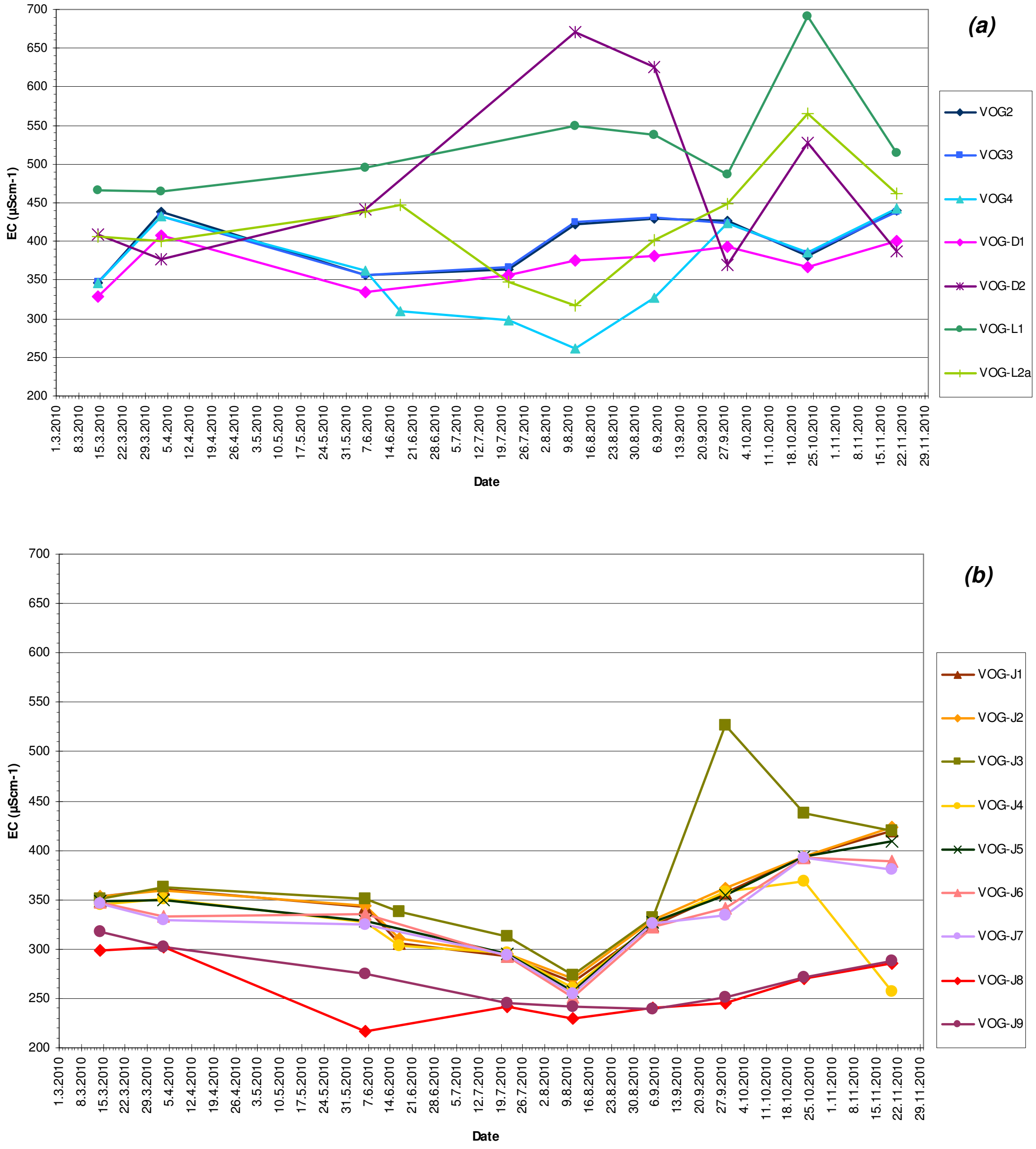


***Figure 5.4: EC at the inflows (a) and at upper and main basin locations (b)***

## 5.6 Cations

$Ca^{2+}$ showed concentrations more than ten times higher compared to $Mg^{2+}$ and $Na^{+}$ *(Figure 5.5-7)*. Concentrations of all three mentioned major cations were higher at the two melioration ditches VOG-D2 and VOG-L1, compared to all other locations. Maximum recorded concentration of $Ca^{2+}$ was 74.1 $mgl^{-1}$, of $Mg^{2+}$ 9.24 $mgl^{-1}$, and of $Na^{+}$ 9.13 $mgl^{-1}$ *(Figure 5.5-7)*. Higher concentrations for all three cations were also recorded at wetland-1 (VOG-J3) in autumn, on 28th of September and 20th of November.

Throughout the sampling period $Ca^{2+}$ concentrations were the lowest at the main basin and upper basin locations (VOG-J1 to J9) *(Figure 5.8-10)*, with a respective average of 31.9 $mgl^{-1}$ and

36.8 mgl$^{-1}$, see *Appendix 2.1-2.16*. Similarly, the average $Mg^{2+}$ and $Na^{+}$ concentrations were the lowest at the upper basin with 2.7 mg Mgl$^{-1}$ and 3 mg Nal$^{-1}$, followed by the main basin, with an average of 3.3 mg Mgl$^{-1}$ and 3.3 mg Nal$^{-1}$. Average concentrations of $Ca^{2+}$ at two wetlands did not show noticeable difference from the upper basin locations, except for a $Ca^{2+}$ concentration peak recorded at wetland-1 in November. On the other hand $Mg^{2+}$ and $Na^{+}$ average concentrations at wetland-1 were slightly higher compared to the upper basin, which is consistent with the concentration peaks showed in Figure 5.9 and Figure 5.10 at wetland-1 in autumn.

$K^{+}$ concentrations were recorded only on three occasions, twice at VogrščEk stream VOG2 with a maximum of 3.95 mgl$^{-1}$, and once at the wetland-2 (VOG-J4), 1.46 mg Kl$^{-1}$. For all other measurements $K^{+}$ concentrations were below the LOD (< 1mgl$^{-1}$).

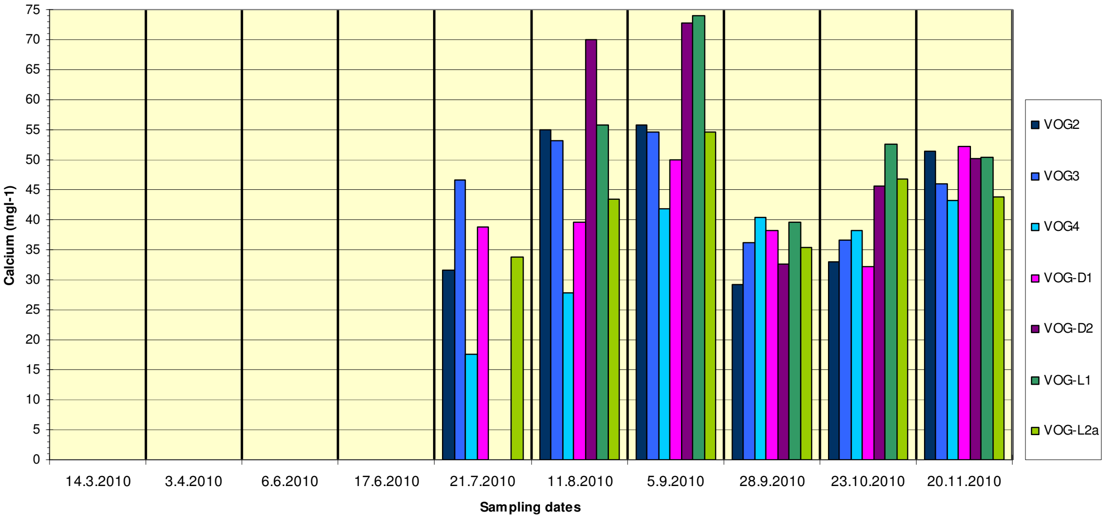


***Figure 5.5: $Ca^{2+}$ concentrations at the inflows***

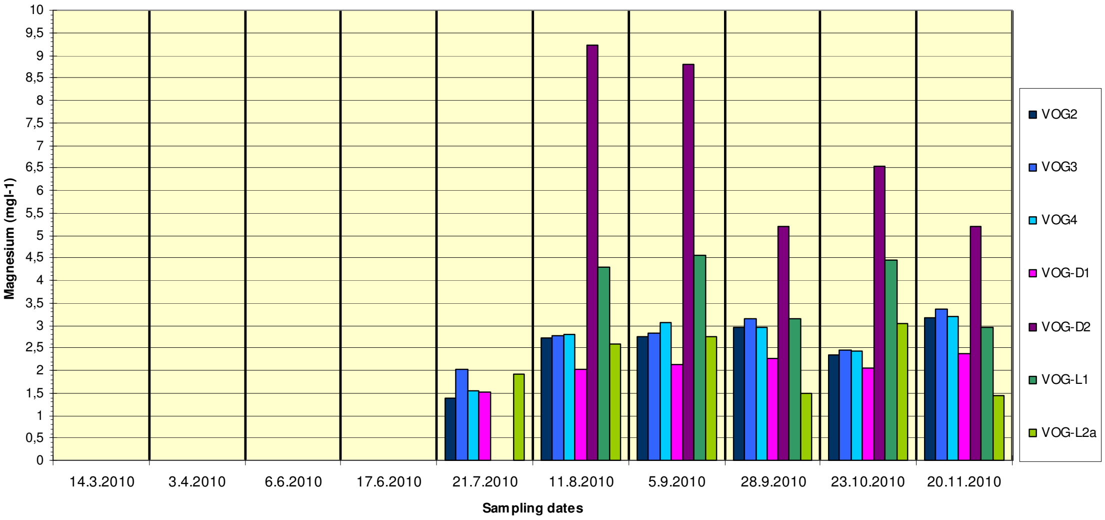


***Figure 5.6: $Mg^{2+}$ concentrations at the inflows***

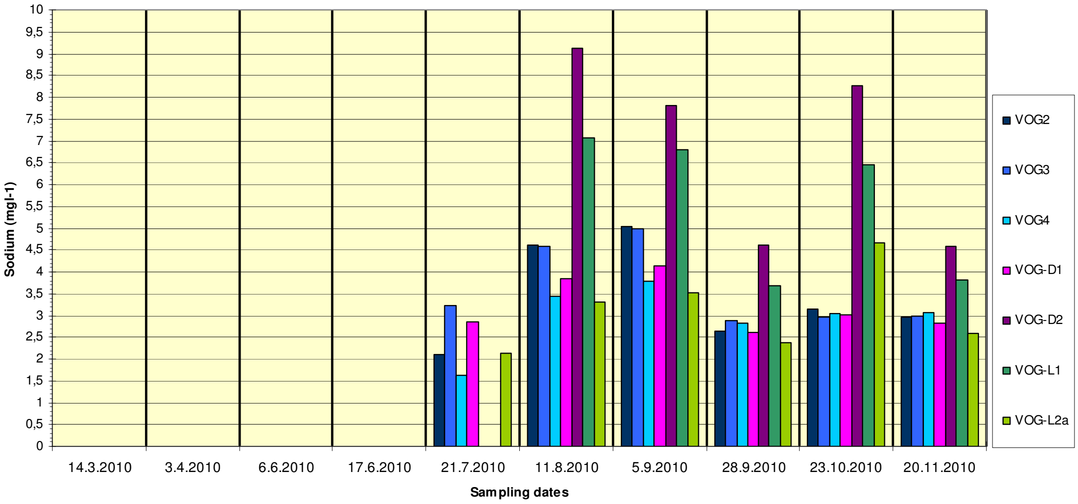


Figure 5.7: $Na^+$ concentrations at the inflows

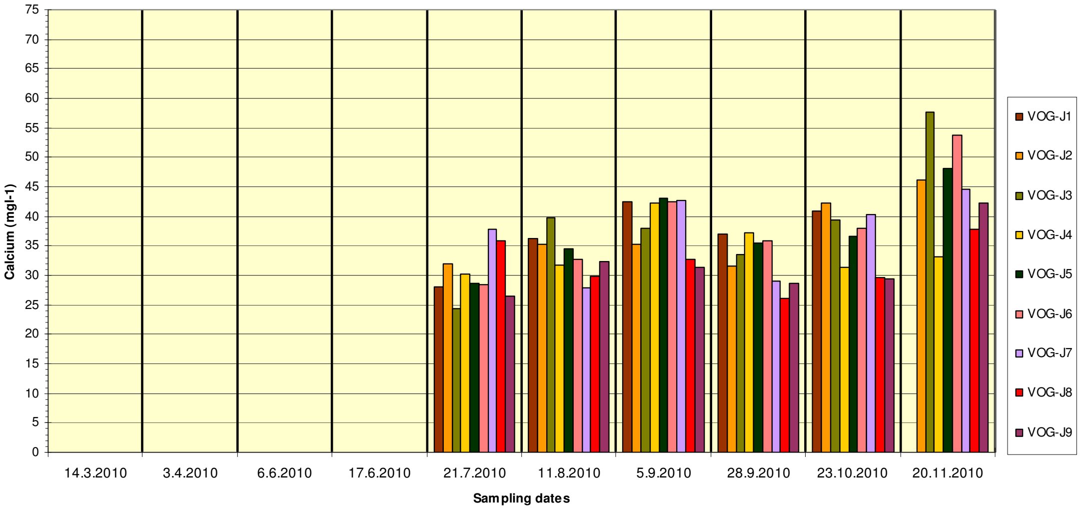


Figure 5.8: $Ca^{2+}$ concentrations at upper and main basin locations

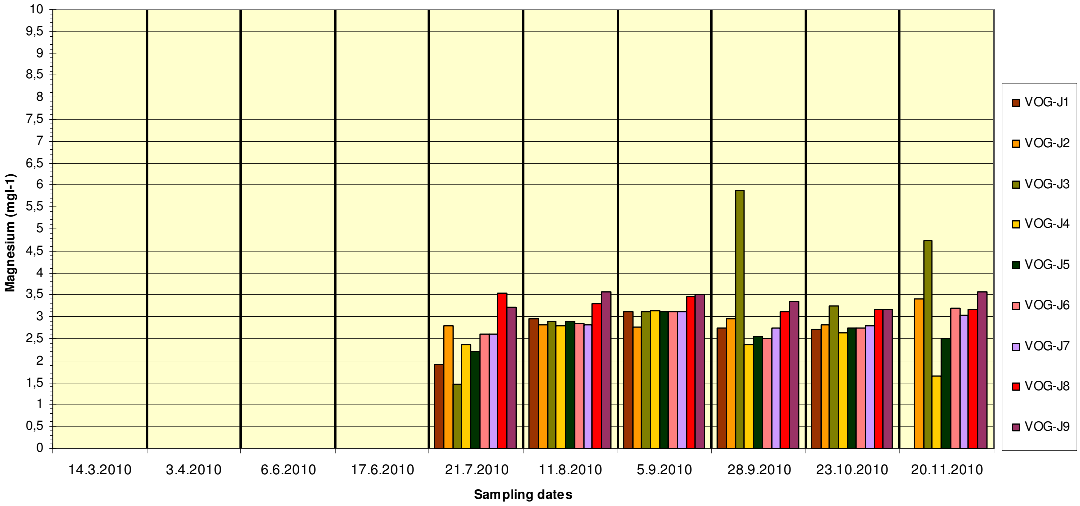


Figure 5.9: $Mg^{2+}$ concentrations at upper and main basin locations

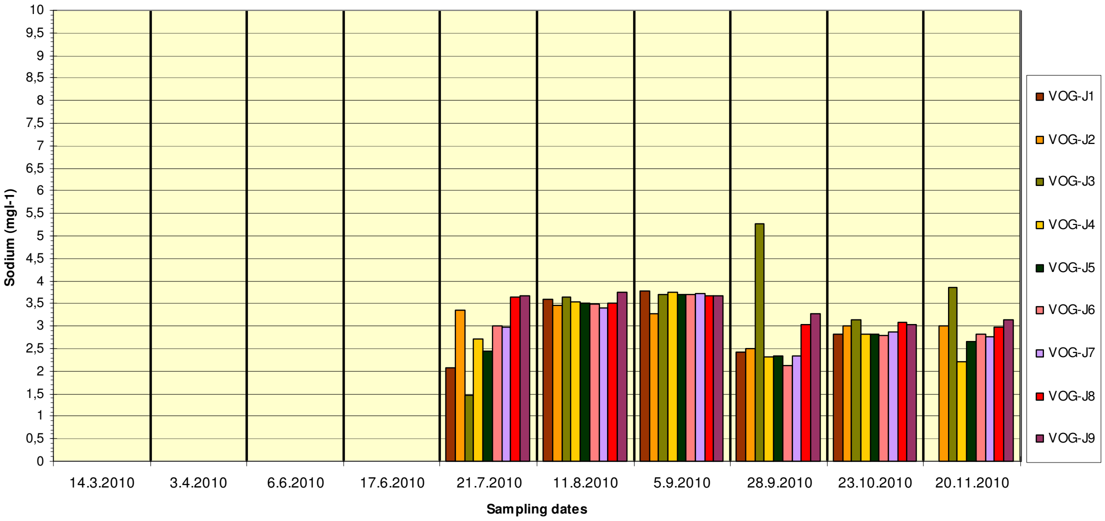


***Figure 5.10: Na$^+$ concentrations at upper and main basin locations***

## 5.7 Anions

Among the anions $SO_4^{2-}$ and $Cl^-$ had the highest concentrations. The highest $SO_4^{2-}$ concentrations were recorded at the melioration ditch VOG-D2 with an average of 15.3 mgl$^{-1}$ and a maximum of 18.6 mgl$^{-1}$ *(Figure 5.11) (Appendix 2.1-2.16)*. Generally higher $SO_4^{2-}$ concentrations with an average of 11.5 mgl$^{-1}$ and a maximum of 13.2 mgl$^{-1}$ were recorded at the main basin (VOG-J8, VOG-J9) *(Figure 5.13) (Appendix 2.1-2.16)*. The two locations VOG2 and VOG3 at the Vogrščcek stream also showed some distinct peaks in $SO_4^{2-}$ concentrations, with a maximum of 14.5 mgl$^{-1}$ *(Figure 5.11)*. $SO_4^{2-}$ concentrations were evidently lower at melioration ditch VOG-L2a with an average of 4.4 mgl$^{-1}$, and at the wetland-1 (VOG-J3) with an average of 5.8 mgl$^{-1}$. Average $SO_4^{2-}$ concentrations at the other upper basin locations and at ditch VOG-L1 did not showed noticeable difference and varied between 7.3 – 8 mgl$^{-1}$.

$Cl^-$ concentrations were higher at the melioration ditch VOG-L1 with an average of 5.7 mgl$^{-1}$ and a maximum of 9.63 mgl$^{-1}$ in April *(Figure 5.12) (Appendix 2.1-2.16)*. Higher $Cl^-$ concentrations were also recorded at the main basin (VOG-J8, VOG-J9) with an average of 4.25 mgl$^{-1}$ *(Figure 5.14)*. The $Cl^-$ concentrations were the lowest at wetland-1 (VOG-J3 and VOG-J2), with a minimum of 1.47 mgl$^{-1}$ Cl. An outstanding high $Cl^-$ peak of 26.9 mgl$^{-1}$ was recorded at VOG-J5 location in June; similarly high concentrations were not recorded before or again at any location.

Concentrations of anions $F^-$ and $Br^-$ were below the LOD for all measurements performed.

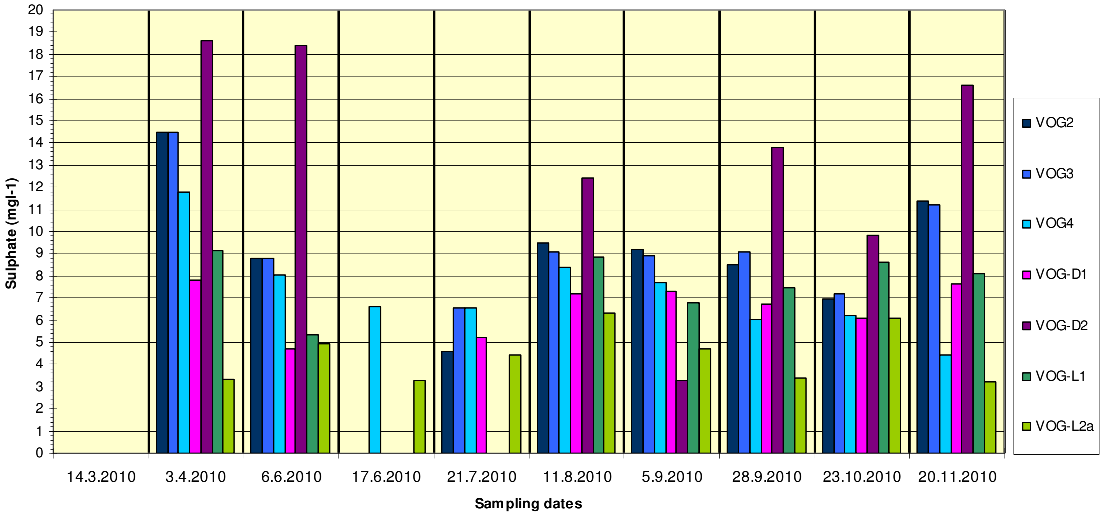


*Figure 5.11: $SO_4^{2-}$ concentrations at the inflows*

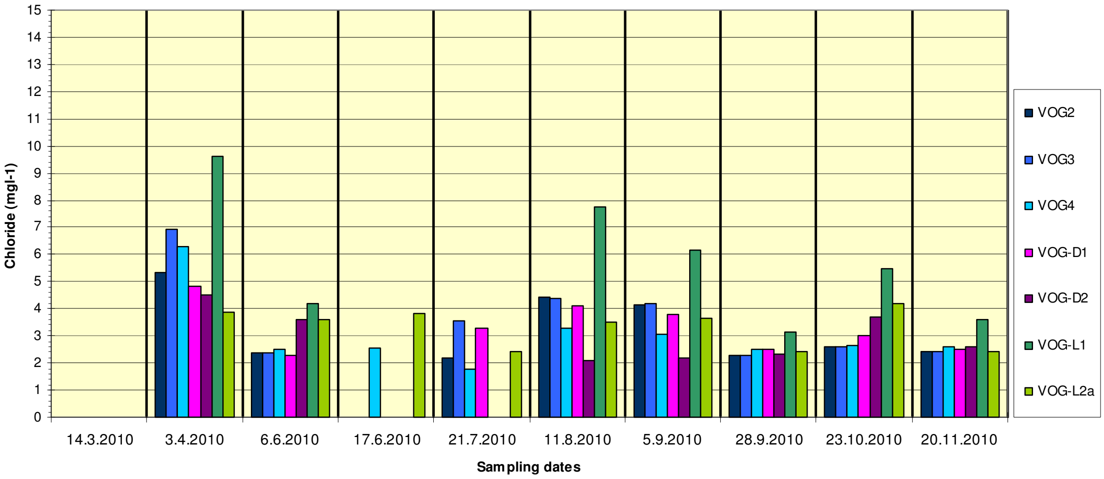


*Figure 5.12: $Cl^-$ concentrations at the inflows*

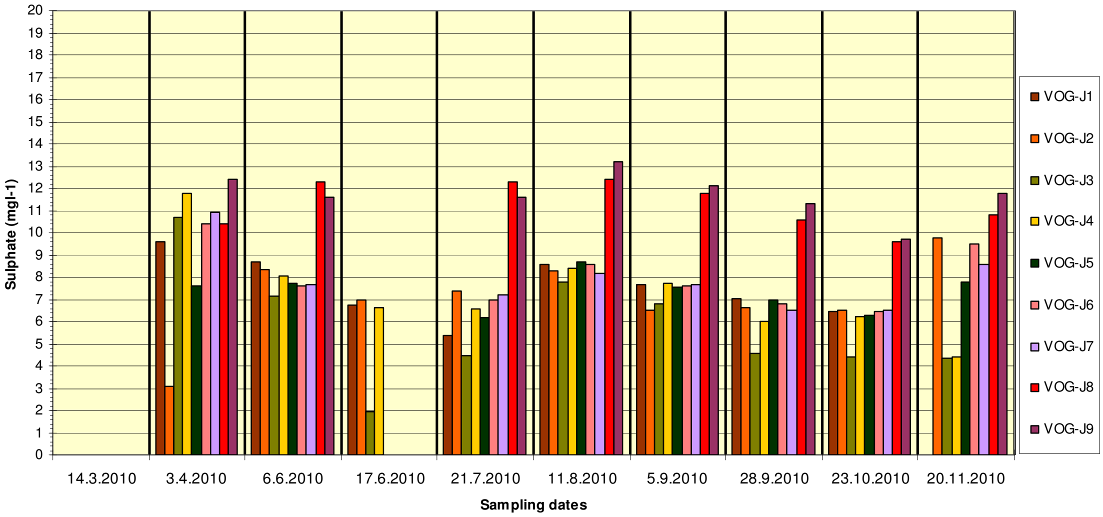


*Figure 5.13: $SO_4^{2-}$ concentrations at upper and main basin locations*

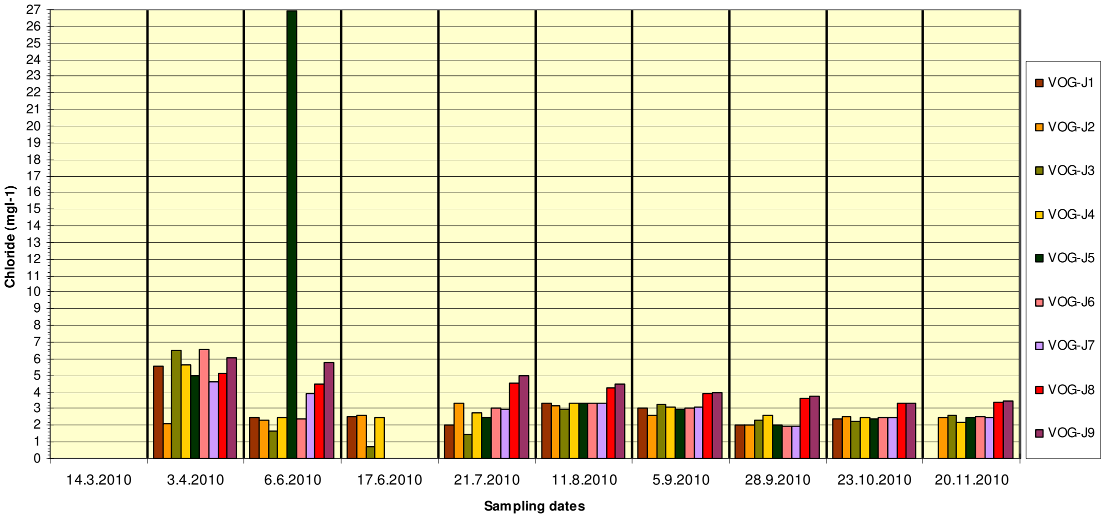


*Figure 5.14: Cl⁻ concentrations at upper and main basin locations*

## 5.8 Dissolved oxygen (DO)

Levels of DO recorded at inflows are shown on Figure 5.15. A difference in the recorded levels can be noted within inflows between the streams (VOG2, VOG3, VOG4 and VOG-D1) and melioration ditches (VOG-D2, VOG-L1 and VOG-L2a). DO levels at streams ranged from a minimum of 7.4 mgl$^{-1}$ to a maximum of 9.53 mgl$^{-1}$ with a saturation range of 72.9 to 90.9 %, respectively *(Appendix 2.1-2.16)*. DO levels recorded at melioration ditches were lower, with a range between a minimum of 0.5 mgl$^{-1}$ in summer and a maximum of 8.2 mgl$^{-1}$ in late autumn. Respective saturation range was between 5.1 and 76.3 %. DO levels at melioration ditches varied and showed distinct ups and downs (see *Figure 5.15)*. DO levels recorded at inflows during the measurements did not reach a 100 % oxygen saturation level *(Figure 5.16)*.

DO levels at the upper and main basin did not vary noticeably, except for the two wetlands. Minimum and maximum DO levels recorded at the both basins were 5.02 mgl$^{-1}$ and 8.8 mgl$^{-1}$, with saturation between 49.6 and 109 %, respectively *(Figure 5.17 and Figure 5.18)*. Levels above 100 % saturation were recorded in August at four reservoir locations – two at the main basin (VOG-J8 and VOG-J9) and two at the upper basin (VOG-J5 and VOG-J6). Average oxygen saturation level at the reservoir location was 75 % *(Appendix 2.4-2.12)*. In general recorded DO levels were higher in summer and tend to decrease towards autumn and winter.

Within the wetland locations (VOG-J3, VOG-J4, and VOG-J2) wetland-1 (VOG-J3) showed the lowest DO levels throughout the measuring period *(Figure 5.17)*, with a minimum of 1.5 mgl$^{-1}$ in August, and an average saturation level of 31.8 %. The DO levels at VOG-J3 increased towards winter, and reached a maximum of 5.7 mgl$^{-1}$ at the end of October. The DO levels at the other two wetland locations (VOG-J2 and VOG-J4) were overall higher than VOG-J3 levels, with an average saturation of 57.8 % *(Figure 5.18) (Appendix 2.5-2.7)*. VOG-J4 showed an oxygen deficiency on the last sampling in November, reaching a minimum of 2.21 $mgl^{-1}$, with respective saturation level of 21.2 %.

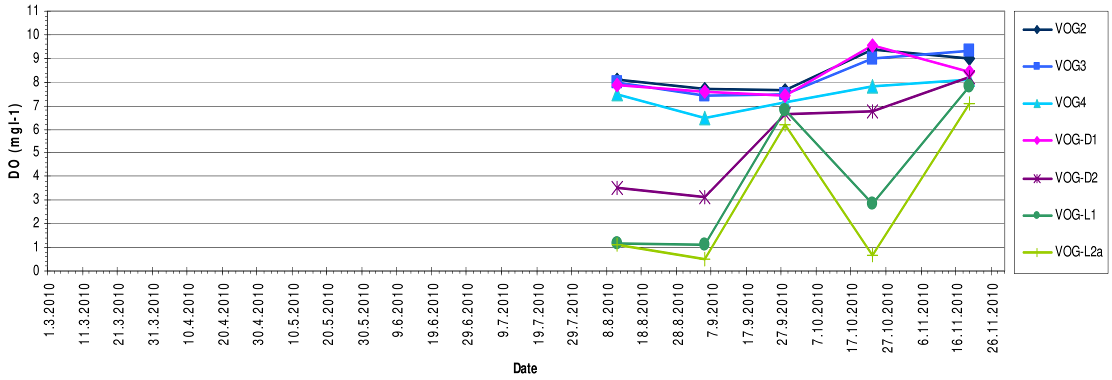


*Figure 5.15: DO levels at the inflows*

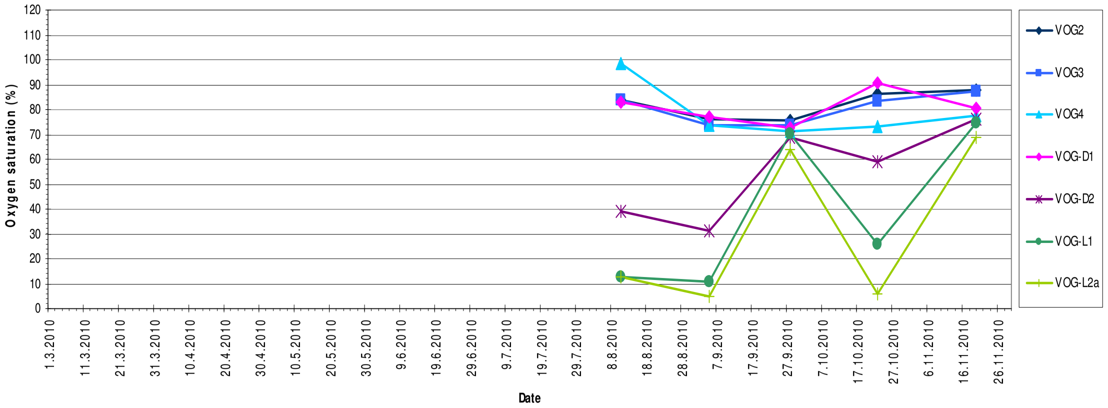


*Figure 5.16: Oxygen saturation levels at the inflows*

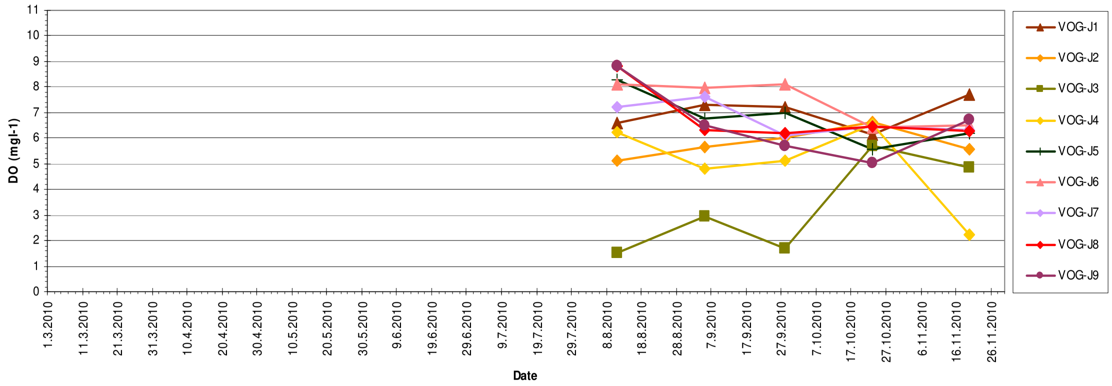


*Figure 5.17: DO levels at upper and main basin locations*

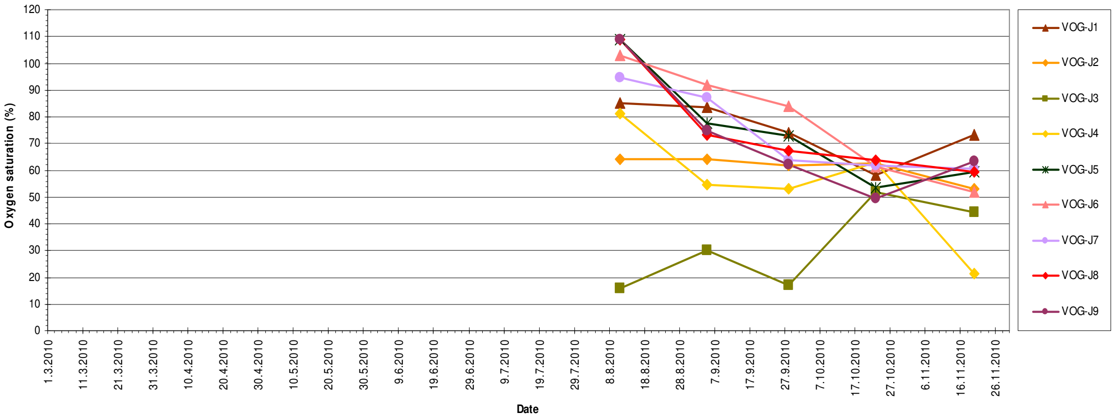


***Figure 5.18: Oxygen saturation levels at upper and main basin locations***

## 5.9 Chemical oxygen demand (COD)

COD levels were the highest at melioration ditch VOG-L2a, at two wetlands (VOG-J3, VOG-J4, and VOG-J2), and at the upper basin in the vicinity of the wetland-1 (VOG-J1). At these locations COD varied noticeably throughout the sampling period *(Figure 5.19)*. The average COD levels at these locations ranged between 9.5 – 13.2 mgl$^{-1}$ $O_2$, with a maximum between 18 – 22 mgl$^{-1}$ $O_2$ *(Figure 5.19) (Appendix 2.4-2.7 and Appendix 2.16)*. The COD levels at other melioration ditches (VOG-D2, VOG-L1) were lower compared to the VOG-L2a and wetlands, with an average of 7.3 mgl$^{-1}$ $O_2$ and a maximum of 10 mgl$^{-1}$ $O_2$ *(Figure 5.19)*.

The lowest COD levels were recorded at the two major inflows VOG2 and VOG-D1, ranging between 3 and 6.4 mgl$^{-1}$ $O_2$; similar levels were recorded at VOG3 stream site, but with two discrepancies of 11 mgl$^{-1}$ in September and of 8 mgl$^{-1}$ in November *(Figure 5.19)*.

COD levels at the other monitored locations were consistent with an average ranging between 9.3 – 9.7 mgl$^{-1}$ $O_2$ *(Appendix 2.1-2.16)*. In general, COD levels were lower in March and April and higher in summer and autumn.

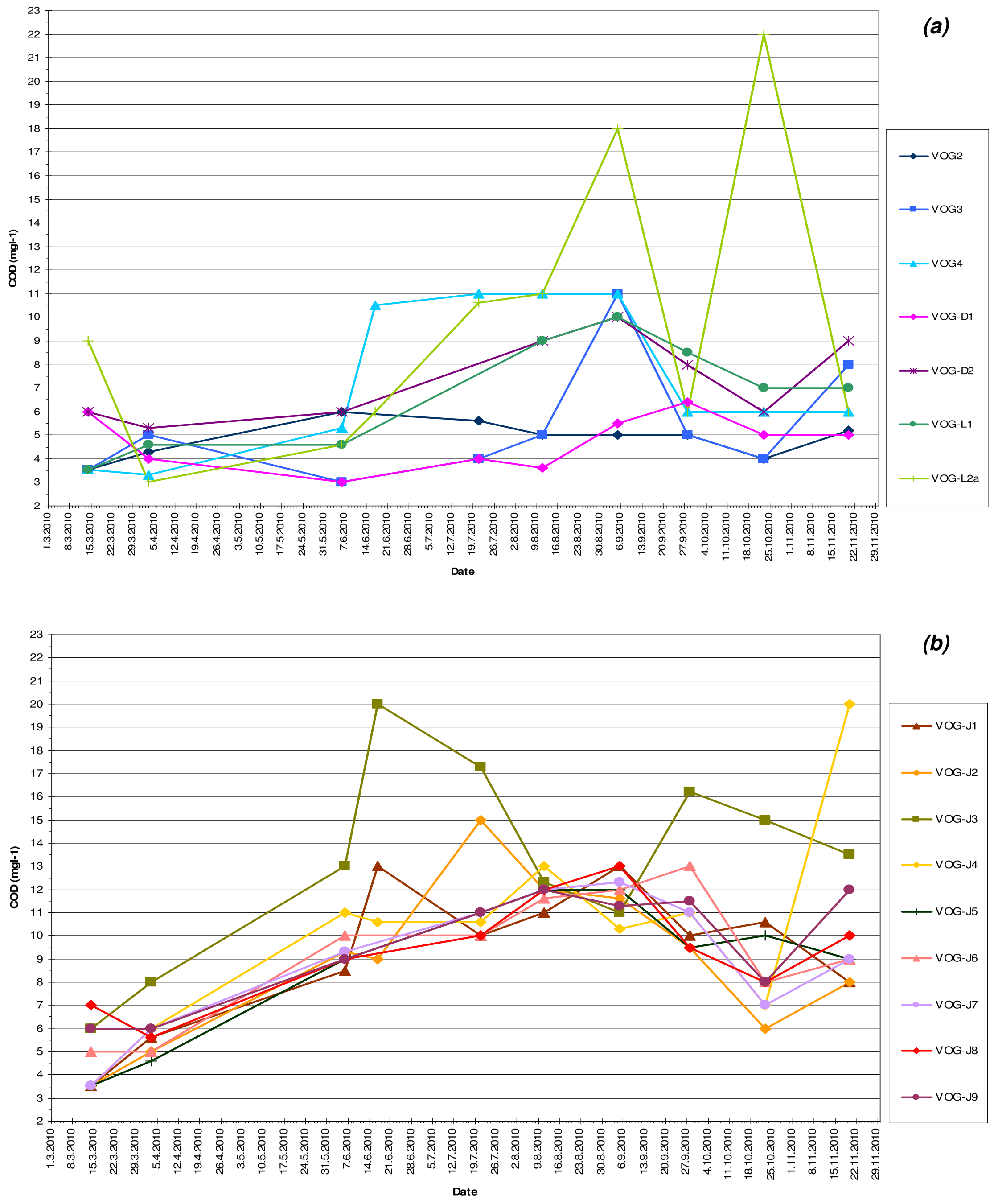


*Figure 5.19: COD levels at the inflows (a) and at upper and main basin locations (b)*

## 5.10 Biochemical oxygen demand (BOD$_5$)

The highest BOD$_5$ level was recorded at melioration ditch VOG-L2a in October, with a maximum above 7 mgl$^{-1}$ O$_2$ *(Figure 5.20)*. BOD$_5$ levels above 5 mgl$^{-1}$ O$_2$ were also recorded in summer months at the inflows (VOG4, VOG-D2, VOG-L1), at wetland-1(VOG-J3, VOG-J2), and at the upper basin (VOG-J6) *(Figure 5.20)*.

In general, $BOD_5$ levels were higher in summer and showed peaks above 3 mgl$^{-1}$ $O_2$ for at least one measurement at all sampling locations, with the exception of the main basin (VOG-J8, VOG-J9). At the main basin $BOD_5$ levels were below 3 mgl$^{-1}$ $O_2$ for all the measurements performed.

The two major inflows VOG-2 and VOG-D1 were never tested for $BOD_5$ due to very low COD levels.

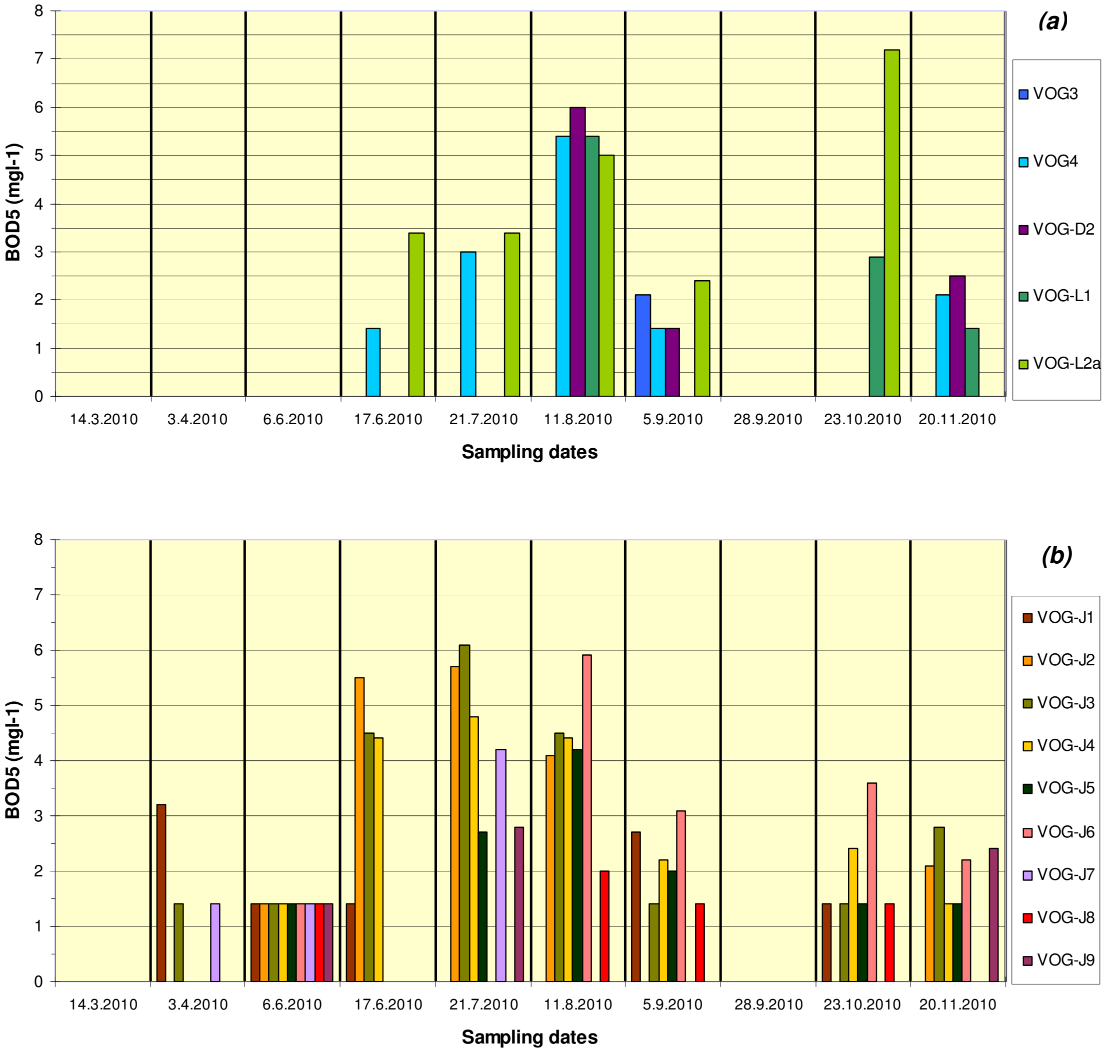
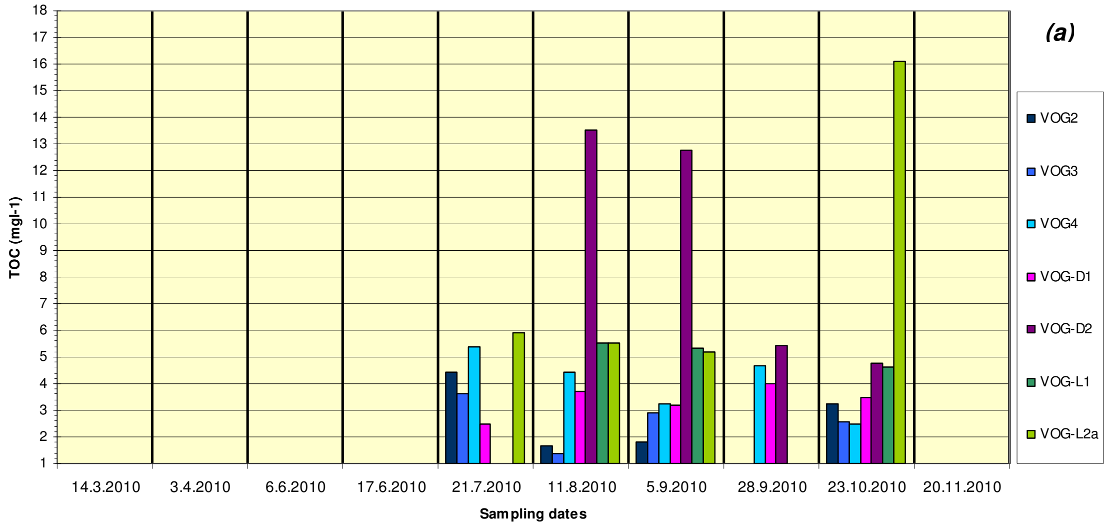


***Figure 5.20: $BOD_5$ levels at the inflows (a) and at upper and main basin locations (b)***

## 5.11 Total organic carbon (TOC)

Due to persistent problems with the analytical instrument we were only able to conclude half of the ten TOC measurements planned. The measurements performed showed considerably higher TOC levels at the two melioration ditches, VOG-D2 and VOG-L2a, and at the wetland-1 (VOG-J3), with respective maximums of 13.51 mgl$^{-1}$, 16.08 mgl$^{-1}$, and 15.73 mgl$^{-1}$ *(Figure 5.21)*. The peaks at VOG-D2 were recorded in summer, while the highest peaks at VOG-L2a and wetland-1 were recorded in autumn.

Among other locations TOC levels did not differ considerably. A slight difference was noticed between TOC levels at the stream inflows (VOG2, VOG3, and VOG-D1), which were lower, with an average of 2.6 – 3.4 $mgl^{-1}$, compared to TOC levels recorded at other basin locations, which had an average between 4.7 and 5.6 $mgl^{-1}$ *(Figure 5.21) (Appendix 2.1-2.16).*



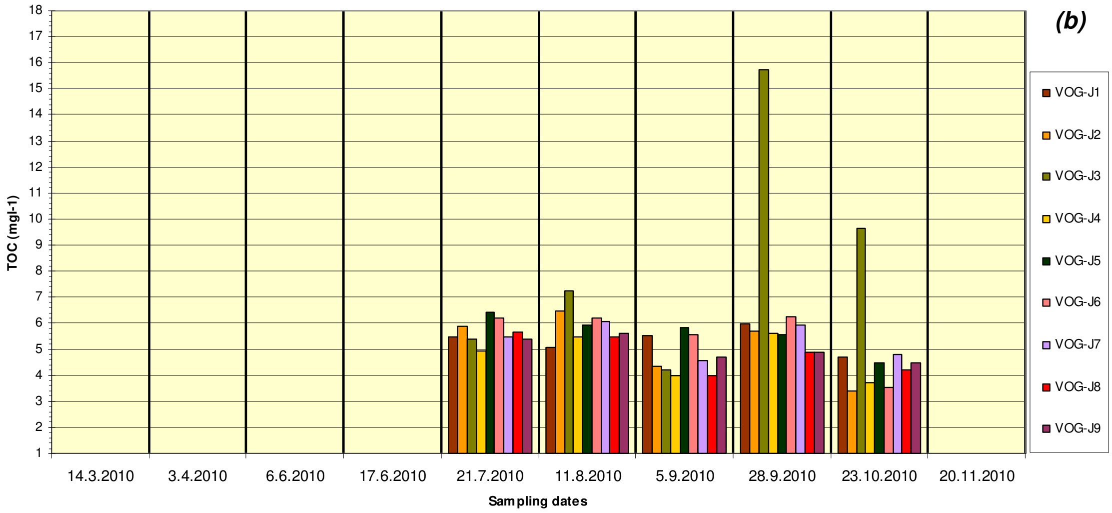


***Figure 5.21: TOC levels at the inflows (a) and at upper and main basin locations (b)***

## 5.12 Nitrogen and Phosphorous

Calculated $NO_3$-N average values at the study area ranged from 0.45 to 1.17 $mgl^{-1}$ *(Appendix 2.1-2.16)*. Higher $NO_3$-N values were recorded at the Dolenjski potok stream VOG-D1 throughout the sampling period, followed by Vogrščček stream locations VOG2, VOG3, and VOG4 *(Figure 5.22)*. Average $NO_3$-N values at these locations ranged between 0.7 and 1.17 $mgl^{-1}$ and were the highest in summer, with maximums of 1.51 $mgl^{-1}$, 1.42 $mgl^{-1}$, and 1.35 $mgl^{-1}$, at VOG-D1, VOG2, and VOG3, respectively. $NO_3$-N values at melioration ditches VOG-D2, VOG-L1, and VOG-L2a were also higher, with the average ranging between 0.62 to 0.83 mgl$^{-1}$; and one outstanding peak of 1.51 mgl$^{-1}$ recorded at VOG-L1 in April *(Figure 5.22)*.

$NO_3$-N values at the upper basin exhibited an average between 0.47 – 0.61 mgl$^{-1}$, with a maximum of 0.79 mgl$^{-1}$ at VOG-J2 *(Figure 5.22)*. The resulting values were recorded in spring and autumn; during summer months the values at all upper basin locations were below LOD. Wetland-1 (VOG-J3) showed $NO_3$-N concentration above LOD (0.51 mgl$^{-1}$) only on one occasion in April *(Figure 5.22)*; for all other measurements $NO_3$-N concentration at wetland-1 remained below LOD.

Average $NO_3$-N values at the main basin (VOG-J8, VOG-J9) were generally lower and ranged between 0.45 – 0.49 mgl$^{-1}$. But, differently from the upper basin, at the main basin $NO_3$-N values persisted above LOD also in summer, except for the 5-th of September as shown in *Figure 5.22*.

Concentrations of $NO_2^-$, $NH_4^+$, and $PO_4^{3-}$ were below LOD for all measurements performed.

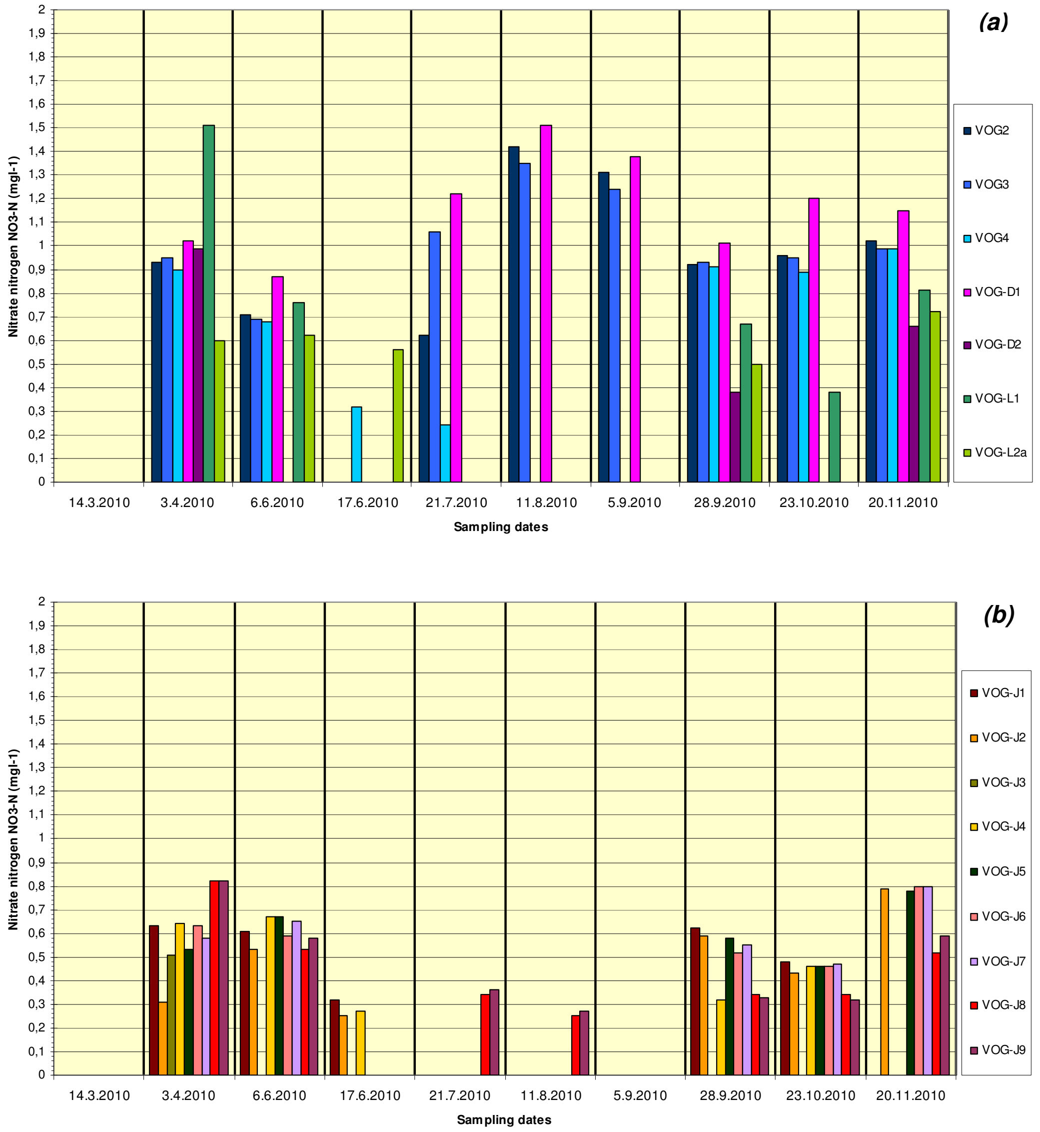


***Figure 5.22: $NO_3$-N values at the inflows (a) and at upper and main basin locations (b)***

## 5.13 Toxicity

The LUMISTox toxicity tests were done two times, on 11th of August and on 28th of September, for all the samples and three to four times for selected samples only. Results varied within locations, among locations, and seasonally *(Appendix 2.1-2.16)*. The inhibition percentage was >20 % on five occasions *(Figure 5.23)*:

- at wetland-1 (VOG-J3) on 17th of June inhibition percentage was 26.54 % and 23.6 % on 5th of September,
- at wetland-2 (VOG-J4) 20,58 % inhibition was recorded on 20th of November,
- at upper basin (VOG-J5) inhibition percentage was 25.82 % on 28th of September,
- and at upper basin (VOG-J6) 21.42 % inhibition was recorded on 28th of September.

Inhibition percentage was > 15 % at inflow VOG4, melioration ditches VOG-D2 and VOG-L1, and at the upper basin VOG-J1, but at each location only on one sampling occasion *(Figure 5.23)*. At other locations bioluminescence inhibition percentage was reduced to <10 %. At sampling performed on 11th of August bioluminescence inhibition dropped to negative values in all samples, except in sample VOG-J7 *(Figure 5.23)*.

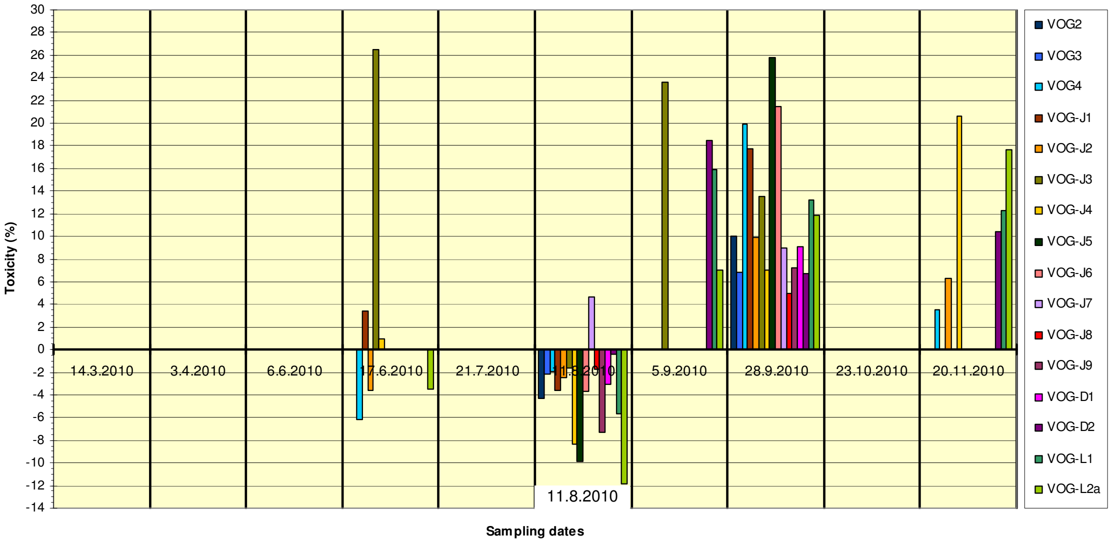
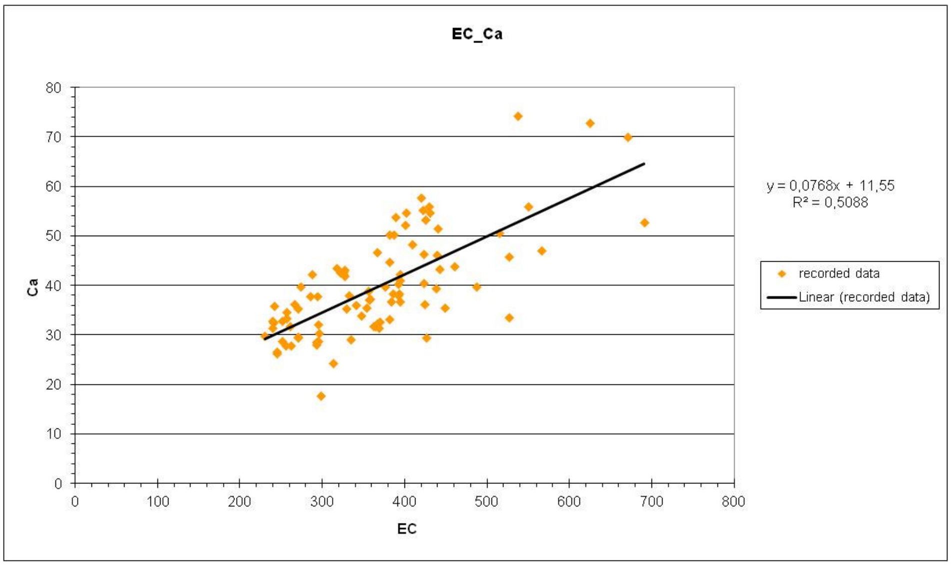
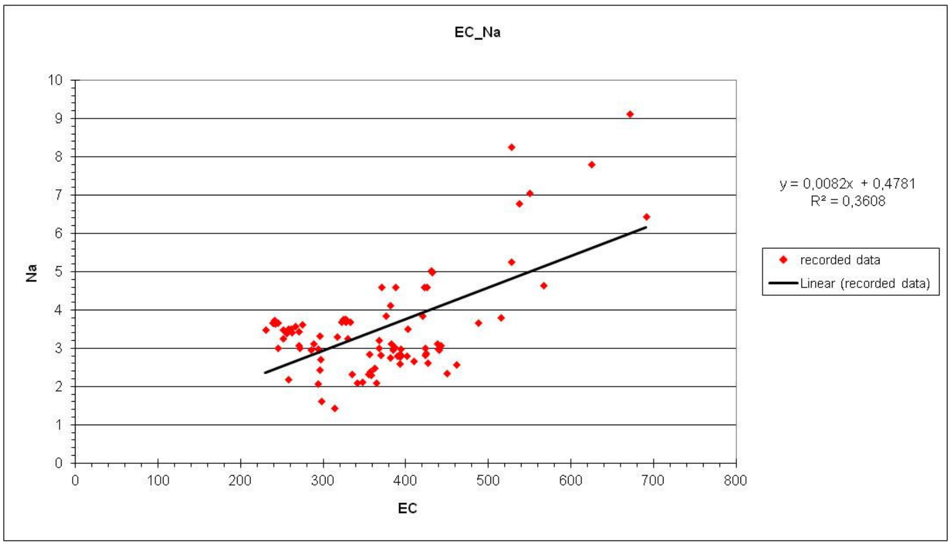


***Figure 5.23: Toxicity measurements results***

## 5.14 Correlations

Linear correlations were made between EC and all major ions, between $Na^+$ and $Cl^-$, $Ca^{2+}$ and $Mg^{2+}$, $Ca^{2+}$ and $SO_4^{2-}$, TOC and COD, EC and $N\text{-}NO_3$. The results showed a positive correlation between EC and $Ca^{2+}$ ($R^2$=0,5), EC and $Mg^{2+}$ ($R^2$=0,25), EC and $Na^+$ ($R^2$=0,36), EC and $N\text{-}NO_3$ ($R^2$=0,2), Na and Cl ($R^2$=0,27), Ca and Mg ($R^2$=0,27) *(Figure 5.24)*. For all the other variables positive correlations were not confirmed.





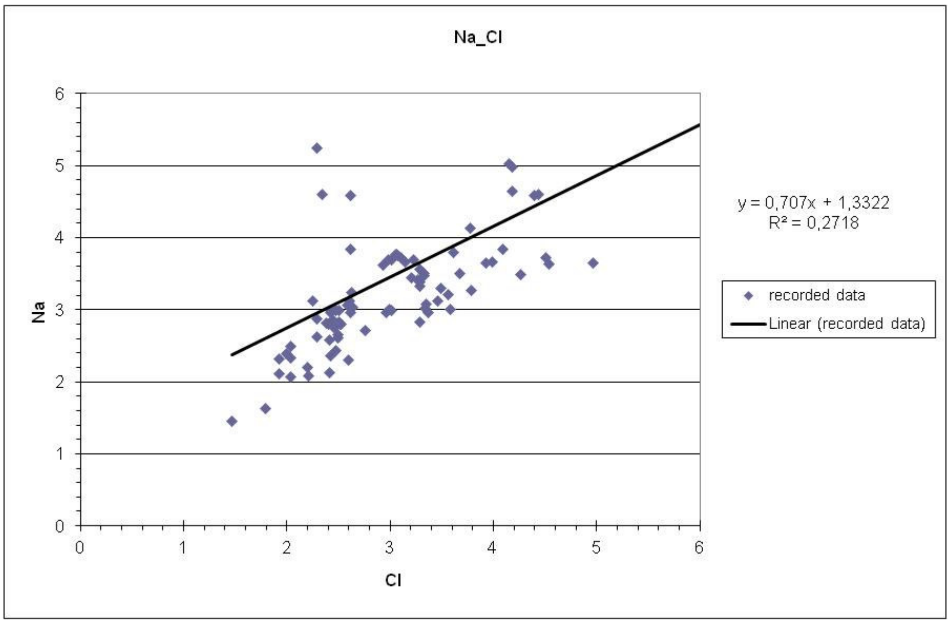


***Figure 5.24: Correlation data between EC and $Ca^{2+}$, EC and $Na^{+}$, and $Na^{+}$ and $Cl^{-}$. Number of samples used for correlation is 78.***

# 6 DISCUSSION

## 6.1 Physical and chemical water quality variables

### 6.1.1 *Water level, air and water temperature*

The amount of precipitation in the region of the Vogršček reservoir in 2010 was 2008 mm (ARSO, 2011a). The maximal relative water level fluctuation during the sampling period was 5 cm. Since the maximum water level fluctuation determined at the upper basin is 3.2 m (Poslovnik…, 2008), we concluded that the relative difference in the water level, which occurred during our study, was due to precipitation. Regarding the results we also concluded that the Črniče Pump facility situated at the upper basin was not in function during our sampling period. As mentioned in the chapter 3.3 we were not able to obtain any information about the Črniče Pump functioning; however, it can be deduced that it was never in function from the fact that it is poorly maintained.

Air temperature was the lowest on the morning 14th of March 2010 (7 °C), and the highest (29 °C) in summer afternoons in June and July 2010 *(Figure 5.1)*. Air temperatures were consistent with data reported by ARSO *(Figure 4.2)* (ARSO, 2011b) and followed a normal and typical pattern for areas within Temperate Zone, with air temperatures rising from spring towards summer, reaching peak in summer, and decreasing from summer towards autumn and winter.

Water temperature followed a generally simple and normal pattern over the sampling period; the temperature constantly increased from spring towards summer, remained high until August and then decreased towards autumn. The variations among single locations depended on site location, i.e. whether sampling locations were in sun or shadow position, and on flow characteristics, i.e. whether the water was stagnant or running. The biggest difference in water temperature was recorded in summer, when the temperature at stream locations was lower compared to the temperatures recorded at both basins locations *(Figure 5.2)*. This is consistent with the fact that major streams collect water that percolates through the vadose zone of carbonate rocks which form the Trnovski gozd plateau at the north of the reservoir drainage basin (Trček, 2005). Among sampling locations only the VOG4 location showed some unexpected data. At the beginning of our study the VOG4 location was selected to represent a point within the inflow area of Vogršček stream into the upper basin. But, instead of showing variations typical for the area of impact the water temperature at VOG4 was entirely consistent with the data recorded at upper basin locations *(Figure 5.2)*. Similar results were observed for some other variables, i.e. EC and DO; suggesting that VOG4 location was actually placed within an upper basin embayment inside the riverine zone as defined by Thornton (1990a) and Wetzel (2001) (see chapter 2.3). According to Ford (1990) and Kimmel et al. (1990) water masses are relatively isolated within embayments and they may function as isolated pockets of temporarily trapped inflowing nutrient load, concentrated primary and secondary production, and intensive trophic interactions. Variables measured at VOG4 showed patterns occasionally consistent with the inflows, on other times more consistent with the upper basin values, and sometimes incompatible with any location. These results suggest characteristics of an embayment within the riverine zone. We believe that the actual impact of Vogršček stream inflow should be observed a few tens of meters upstream, in the Vogršček stream and melioration ditch VOG-L1 confluence area *(Figure 3.4).*

### *6.1.2 PH, electrical conductivity (EC) and major ions*

pH values recorded at the study area during the period of sampling was neutral to slightly alkaline, with a minimum of 6.9 at wetland-1 and a maximum of 8.8 at upper basin (VOG-J5) *(Figure 5.3).* Melioration ditches and wetlands had lower pH average values (7.7) compared to average streams and reservoir values (8.1). Recorded pH values match the pH range of most natural waters and lakes, which is between 6.0 and 8.5 according to Chapman and Kimstach (1998) and Wetzel (2001). They corresponded entirely to the pH values recorded at the reservoir and inflows in the previous study of Luznik and Vrhovšek (1992). The pH values recorded at the upper and main basin also corresponded to the pH values recorded at the reservoir for other water quality monitoring performed in years from 2003–2010 cited in the chapter 1.1 (Poročilo o preskusu, 2007, 2008, 2009, 2010). All the reports presented a similar pattern that was observed also during our study; the pH values were higher in spring and summer and tend to decrease towards autumn. Luznik and Vrhovšek (1992) concluded that higher pH values of the basin-water surface (epilimnium) can be partly attributed to intensified photosynthesis by phytoplankton, which is consistent with explanation for diel and seasonal variations in pH values according to Chapman and Kimstach (1998) and Wetzel (2001).

The highest EC recorded at our study was 691 µScm$^{-1}$ *(Figure 5.4).* Inflows showed higher and more variable EC values (average about 422 µScm$^{-1}$) compared to the upper and main basin, which is consistent with Luznik and Vrhovšek (1992) study. Within both basins, EC values recorded at upper basin were higher (average about 340 µScm$^{-1}$) than those recorded at main basin (average about 265 µScm$^{-1}$). Compared to other water quality monitoring reports about EC data at upper and main basin (ARSO, 2007, 2008, 2009, 2010; Monitoring površinskih voda..., 2007, 2008, 2009, 2010, 2011; Poročilo o preskusu, 2007, 2008, 2009, 2010) the EC values recorded in our study were generally higher, but showed a similar pattern; EC values at the upper and main basin were higher in spring, decrease during summer and were inclined to increase again towards winter. A similar pattern was observed from Carvalho and Kirika (2005) in the Loch Leven case study, but wasn't further discussed. We believe that the increased EC values in spring and autumn period can be attributed to higher precipitations in these seasons *(Figure 5.1)* and consequently, to increased surface runoff from the drainage area towards the reservoir. According to Chapman and Kimstach (1998) EC of most freshwaters ranges from 10 to 1000 µScm$^{-1}$, and may exceed 1000 µScm$^{-1}$, especially in polluted waters, or those receiving large quantities of land run-off. EC is a measure of the ability of a solution to carry electrical current and is dependent upon the presence of ions in solution, consequently, the measurement of EC provides an indication of total dissolved solids, and major ions for a given water body (Chapman and Kimstach, 1998; Twort et al., 2000). Because of its strong relation to major ion composition of fresh waters, the latest still dominated by rock weathering and sea spray (Robards et al., 1994), any comparison of EC values among different study areas is questionable; however, it might be reasonable when discussing cases within the same area and very similar drainage basin characteristics. For example, EC range from a study performed at Turkwel Gorge reservoir in Northern Kenya by Kokut et al. (1999) was 160–200 µScm$^{-1}$. The range is very low compared to EC range recorded in our study, but compared to similar African reservoirs the result actually placed the reservoir into a group of reservoirs with a relatively high conductivity. Jørgensen et al. (2005) suggest that 'low conductivity' means a value below 750 µScm$^{-1}$ at least 95 % of the time, which is consistent with DWD (1998), which determines that the EC limit for water intended for human consumption is 2500 µScm$^{-1}$. EC data are generally used at water quality monitoring to establish a possible pollution zone, where other measurements should then be focused on (Chapman and Kimstach, 1998; Twort et al., 2000). In our study EC values were generally higher and quite variable at streams and melioration ditches, which suggest further analyses should focus on these locations. The EC peaks recorded at melioration ditches in July and August *(Figure 5.4)* are likely due to increased evaporation and low precipitation during the summer.

The highest concentrations of all the measured major ions $Ca^{2+}$, $Mg^{2+,}$ $Na^+$, $SO_4^{2-}$, and $Cl^-$ were recorded at the two melioration ditches VOG-D2 and VOG-L1. The cations concentrations were also higher at the wetland-1, while at upper and main basin the cations concentrations were lower. Differently, for the anions the concentrations were also higher at the main basin beside the two melioration ditches, and were the lowest at wetland-1. The $Na^+$ and $Cl^-$ concentrations recorded on 5th of September at the upper basin *(Figure 5.10 and 5.14)* were consistent with the concentrations recorded during the monitoring performed on 7th of September by the Institute for Health Care Nova Gorica for the facility operator (Poročilo o preskusu, 2010). Other major ions concentrations were not measured for any monitoring or study performed at the reservoir or inflows and consequently no comparison can be made. There are some basic facts about the presence and study of major ions in surface waters we would like to mention in our discussion. Major ions are naturally present in surface waters and their concentrations are very variable due to local geological, climatic and geographical conditions (Chapman and Kimstach, 1998; Wetzel, 2001). They enter surface waters with the rock and soil weathering and drainage processes in surrounding area and with atmospheric deposition. Besides being a required nutrient of normal metabolism of living biota, mostly as micronutrients, major ions play a significant role in the cycling of other nutrients, productivity, and biotic distribution (Wetzel, 2001). The concentrations of major ions in surface waters may increase by human activity, e.g. sewage and industrial effluents, wastewater treatment, use of salts for icy roads in winter, agricultural run-off, and rain acidification, which can significantly alter the water ecosystem (Chapman and Kimstach, 1998; Twort et al., 2000; Wetzel, 2001).

In order to meet the directions of WFD several studies were conducted in UK about water quality of surface waters especially in agricultural regions, which included major ions concentrations research in order to determine a possible impact of human activities on water ion composition (Curtis et al., 2005; Neal et al., 2008; Howden, et al. 2009). Some interesting studies were performed by Evans et al. (2005) and Oulehle and Hruška (2009) about increase of dissolved organic matter in upland surface waters in England and in drinking water reservoirs in Czech Republic, which was apparently connected with decrease of soil and water sulphate concentrations. By studying several potential drivers of dissolved organic matter rising trends, including air temperature, rainfall, etc., they concluded that magnitude of dissolved organic matter increase was significantly associated with declines of sulphur deposition. However, performing the necessary analyses to determine the possible increase of single major ion concentrations that could be induced by anthropogenic activities was beyond the purpose of this study. As mentioned above when discussing EC values, major ions concentrations are highly depended on local geology and climate and any comparison with other studies from a different area are questionable.

However, based on results we can conclude that concentrations of major ions measured at our study are consistent with data for global average chemical composition of unpolluted rivers and variations in composition according to drainage from dominant rock type as listed by Wetzel (2001, p:171). Regarding the higher major ions concentrations recorded at two melioration ditches (VOG-D2, VOG-L1) we sustain that in order to determine their natural occurrence or possible anthropogenic origin, a detailed target research of major ions concentrations and their sources within the Vogršček drainage basin area should be performed.

We conclude this chapter acknowledging that we were not able to prove a reliable positive correlation between EC and major ions concentrations. The highest correlation between EC and $Ca^{2+}$ values ($R^2$=0,5) is indicative, suggesting $Ca^{2+}$ has the strongest influence on EC values. At this point we need to emphasize that a drainage basin is a complex system where all the characteristics and processes are directly or indirectly linked, including meteorological and weather conditions, geological structure, hydrological characteristics to physical and chemical properties of elements, etc. Any natural or anthropogenic influence within the drainage basin will affect the system (Wetzel, 2001; Pepper et al., 2006). Since these processes are not constant in place and time, the impacts will probably not show the predicted pattern as it is common for laboratory research performed under constant conditions. $Ca^{2+}$ is highly present in sediment rocks within the Vogršček drainage basin area (Trček, 2005), and this is the main reason for $Ca^{2+}$ higher concentrations and better correlation result compared to other measured ions. Other ions might not have showed the expected correlation result for different reasons, either due to their mobility in the water solution and lower presence or possibly, due to incoherent measurements during the first four sampling months and other influences not studied or confirmed. These facts should be investigated in further research combined with flow and total dissolved solids (TDS) measurements, which were not performed at this study.

We also repeated the analysis for the outstanding $Cl^-$ peak of 26.9 $mgl^{-1}$ recorded at VOG-J5 location in June and the measured result was confirmed. We were not able to find a proper explanation for this single event.

### 6.1.3 Dissolved oxygen (DO)

Oxygen is the most fundamental parameter of lakes and streams, aside from water itself. It is essential to the metabolism of all aerobic aquatic organisms and influences nearly all chemical and biological processes within water bodies (Chapman and Kimstach, 1998; Wetzel, 2001). Variations in DO levels in surface waters can occur seasonally or daily, in relation to temperature (solubility of oxygen in water decreases as temperature increases) and biological activity (e.g. photosynthesis and respiration) (Chapman and Kimstach, 1998).

Increased photosynthesis is probably the cause of oversaturated DO levels recorded at the upper and main basin in August *(Figure 5.17)*. Similarly oversaturated levels were reported at the Vogšček reservoir occasionally in summer and autumn in the past (Luznik and Vrhovšek, 1992; ARSO, 2007, 2008, 2009, 2010; Monitoring površinskih voda..., 2007, 2008, 2009, 2010, 2011; Poročilo o preskusu, 2007, 2008, 2009, 2010). DO levels recorded in our study if compared to results in cited reports, are noticeably lower, with levels ranging between 5 and 8.8 $mgl^{-1}$ at basins locations, 7.4 – 9.53 $mgl^{-1}$ at streams, 0.5 – 8.2 $mgl^{-1}$ at melioration ditches and 1.5 – 5.7 $mgl^{-1}$ at the two wetlands; while in cited reports the DO levels at streams and melioration ditches remained above 6 $mgl^{-1}$ (Luznik and Vrhovšek, 1992) and at the basins locations ranged between 7 and above 11 $mgl^{-1}$ (Luznik and Vrhovšek, 1992; ARSO, 2007, 2008, 2009, 2010; Monitoring površinskih voda..., 2007, 2008, 2009, 2010, 2011; Poročilo o preskusu, 2007, 2008, 2009, 2010). Oxygen depletion recorded at melioration ditches (VOG-L1 and VOG-L2a) and two wetlands (VOG-J3 and VOG-J4) on 5th of September and 23rd of October *(Figure 5.15 and 5.17)* can be partially attributed to lack of precipitation and higher evaporation losses in summer, and intensified decomposition processes at these locations in autumn. But, considering the data of DO measurements in cited reports and on average noticeably lower DO levels recorded at our study area, we believe DO deficiency might represent a serious problem at Vogrščček reservoir within years. At the time of our research we were not able to obtain any data about oxygen dynamics and stratification within the upper basin. We doubt these studies were performed. Good 'oxygen state' is fundamental for a healthy aquatic environment and DO dynamics within the upper and main basin should be observed and studied carefully in order to ensure a successful managing of the facility. According to Chapman and Kimstach (1998) DO levels indicating less than 80 % saturation in drinking water can usually be detected as a result of poor odour and taste; DO concentrations below 5 $mgl^{-1}$ may adversely affect the functioning and survival of biological communities and below 2 $mgl^{-1}$ may lead to the death of most fish. Considering these facts melioration ditches and wetland-1 with DO levels as low as 0,5 $mgl^{-1}$ are not a potential habitat for living biota. Figure 6.1

shows DO level range with minimum, maximum and mean value at single sampling locations; high variability in DO levels at melioration ditches and wetlands can be observed.

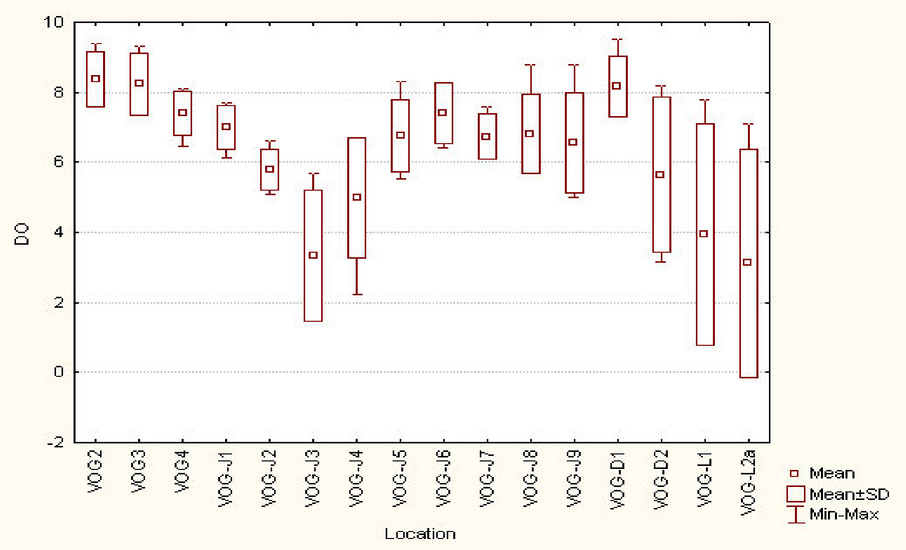


***Figure 6.1: DO level range at single locations with marked minimum, maximum and mean value***

Determination of DO concentrations is an essential part of water quality monitoring and assessments, and a central parameter of all studies conducted about surface water quality for different proposals, because it points out the gravity of pollution. DO can be used to indicate or get information about the degree of organic pollution, the degradation of organic substances and the level of self-purification of the water (Chapman and Kimstach, 1998).

At this point we acknowledge an important fact concerning our further discussion. In order to get a better insight in the physical and chemical state of the Vogrščček reservoir and its drainage basin we wanted to compare the obtained results with respective data published in studies performed at other natural lakes and reservoirs in Slovenia and neighbouring countries. Unfortunately, we were only able to obtain data from lakes and reservoirs in Slovenia which are part of regular water quality monitoring in published ARSO reports (ARSO, 2007, 2008, 2009, 2010). We were not able to find any study about a Slovenian or nearby reservoir dealing with water quality parameters and ecological state of the reservoir and its drainage area. In fact, we found very little published studies linked to water quality and ecological state of reservoirs at all. For this reason we had to focus our research and our discussion on what was performed and published so far, which is water quality monitoring data published in ARSO reports and scientific papers about studies performed at reservoirs worldwide. In our further discussion we compare the results of water quality variables measured at our study (DO, COD, BOD, TOC and $NO_3^-$) with the results recorded at chosen Slovenian lakes and reservoirs, and with the data published in chosen studies from different parts of the world. The latest might not seem very reasonable at first sight; however, review of these studies confirmed what was one of the aims of this study:

- that despite climate, topographic, geologic and other natural characteristics, the pollution sources affecting water quality and ecological state of reservoirs are more or less the same from Mediterranean and Northern Europe to Mexico and China, and these sources are: untreated domestic wastewaters, industrial discharges, agricultural activities and improper reservoir managing, and
- that the natural characteristics condition the reservoir response to these impacts.

The DO levels recorded at our study were compared with DO values recorded in the epilimnium of two Slovenian alpine lakes – Bohinjsko and Blejsko jezero, and two Slovenian reservoirs – Velenjsko and Šmartinsko jezero. Among these four only Bohinjsko jezero was determined to be in an 'ecologically good state' in 2008 (ARSO, 2009). At the two natural lakes the DO levels were constantly above 10 $mgl^{-1}$, while the two reservoirs exhibited a slightly higher average values compared to those recorded at our study, with a minimum of 7.5 $mgl^{-1}$.

In literature really severe oxygen depletion is reported for study cases of heavily polluted surface waters. For example, in the case of Lerma river high course which ends within reservoir Alzate in Mexico (Fall et al., 2007) oxygen was found exhausted (< 0,5 $mgl^{-1}$) almost all along the high course of the river. Only four of the six tributaries and a lagoon at the origin of the river were in relatively 'better conditions', with DO values ranging between 2 and 8 $mgl^{-1}$. The river was found to be heavily polluted with untreated domestic wastewater, industrial discharges and because of agricultural activities. Another case of intensive pollution is a study performed at the Lake Mariut in Egypt more than twenty five years ago (Saad et al., 1984). DO levels recorded at that time at measured stations at Lake Mariut ranged between 1.4 and 6.5 $mgl^{-1}$. The oxygen depletion at the Lake Mariut was so severe that authors reported about the unpleasant odour of $H_2S$ that could be smelled at some points of the lake. It was attributed to the anaerobic decomposition of organic loads where DO was depleted (Saad et al., 1984).The DO ranges of these two studies are similar to DO values recorded at melioration ditches, wetlands and occasionally basins locations in our study, suggesting oxygen conditions at Vogršček reservoir should be further investigated. Some studies also report about significant DO decrease in the surface water at the corresponding reservoirs, which occurred due to mixing of DO deficient water during overturn periods (Soltero et al., 1973; Kotut et al., 1999). This emphasizes the importance of performing a case study of the oxygen dynamics within the reservoir to be able to ensure a proper management of the facility.

On the other hand oxygen deficiency was not confirmed for three other cases of eutrophic lakes: naturally eutrophic Scottish Loch Leven (Carvalho and Kirika, 2005) and two Turkish lakes found eutrophic due to anthropogenic organic loads (Karakoς, et al., 2003; Gunes, 2008). DO values at these lakes were constantly above 8 $mgl^{-1}$ and oxygen saturation above 85 %. Studies suggest that the most severe oxygen depletion usually occurs in surface waters submitted to organic wastes pollution, while the response of surface waters to eutrophication varies significantly among water bodies and is highly dependent on single water body hydrological and morphological characteristics. However, long term excessive nutrient loading will gradually result in oxygen deficiency of a water body, altered anoxic conditions and adverse conditions for aquatic biota.

### 6.1.4 Chemical oxygen demand (COD), biochemical oxygen demand ($BOD_5$) and total organic carbon (TOC)

COD, BOD and TOC variables are normally measured together and used for comparative purposes as indicators of the amount of organic matter present (Bartram and Balance, 1996). Various authors, e.g. Chapman and Kimstach (1998), Wetzel (2001), Jørgensen et al. (2005) and others, suggest that in unpolluted waters COD levels range up to 20 $mgl^{-1}$ $O_2$ and $BOD_5$ levels are typically around 2 $mgl^{-1}$ $O_2$ or less. TOC content of natural surface waters, such as rivers and oligotrophic lakes, is generally in the rage of 1 – 30 $mgl^{-1}$. At our study the melioration ditches VOG-L2a and VOG-D2 exhibited the highest levels for all three variables, with respective maximums of 22 $mgl^{-1}$ (COD), >7 $mgl^{-1}$ ($BOD_5$) and 16.08 $mgl^{-1}$ (TOC). Similarly high levels were recorded at wetland-1 (VOG-J3). The levels of COD, $BOD_5$ and TOC were higher also at other wetland locations (VOG-J4, VOG-J2) *(Figure 5.19-5.21)*. In general, at these locations the levels were not only higher compared to other locations but also varied evidently throughout the sampling period, which can be observed on Figure 6.2 – 6.4. Considering the fact that these are also locations of the lowest recorded DO levels the results suggest that conditions of organic matter overload might be present. Higher TOC levels recorded at wetlands could be attributed also to the fact that higher TOC values are generally encountered in very productive habitats, such as shallow waters of wetlands (Wetzel, 2001).

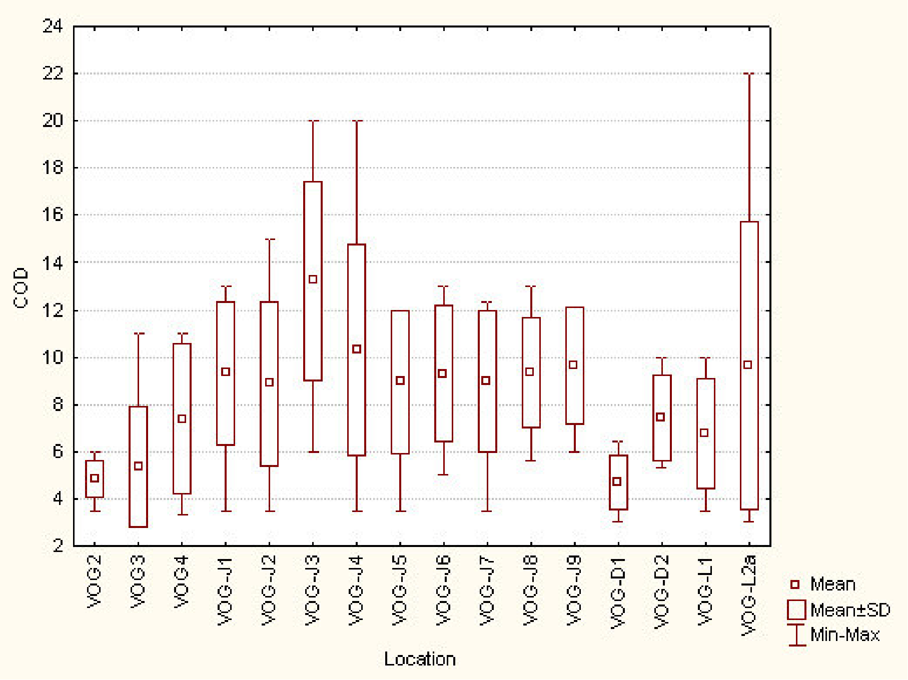


**Figure 6.2: COD level range at single locations with marked minimum, maximum and mean value**

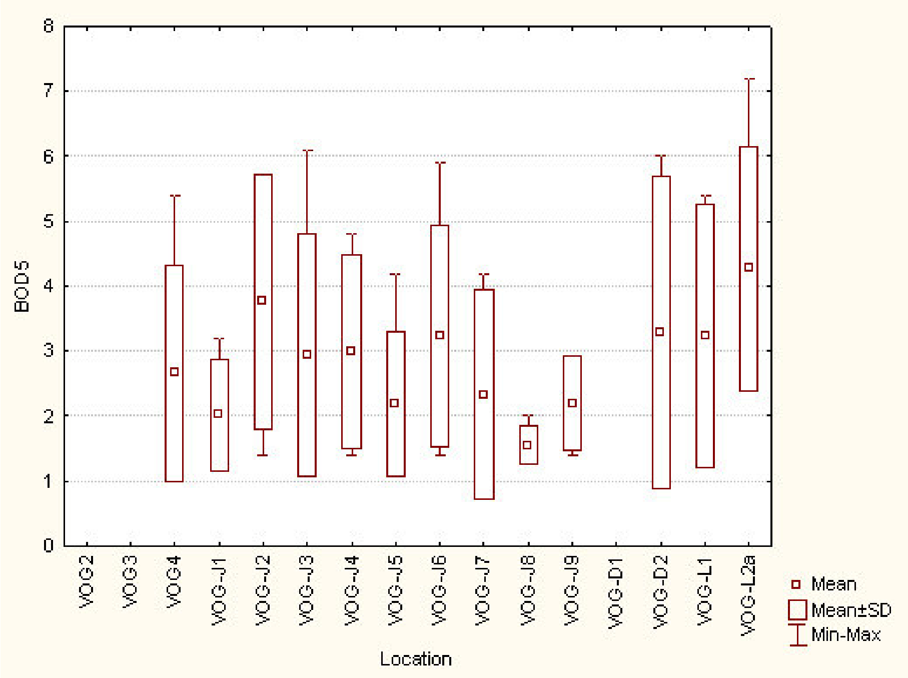


***Figure 6.3: $BOD_5$ level range at single locations with marked minimum, maximum and mean value***

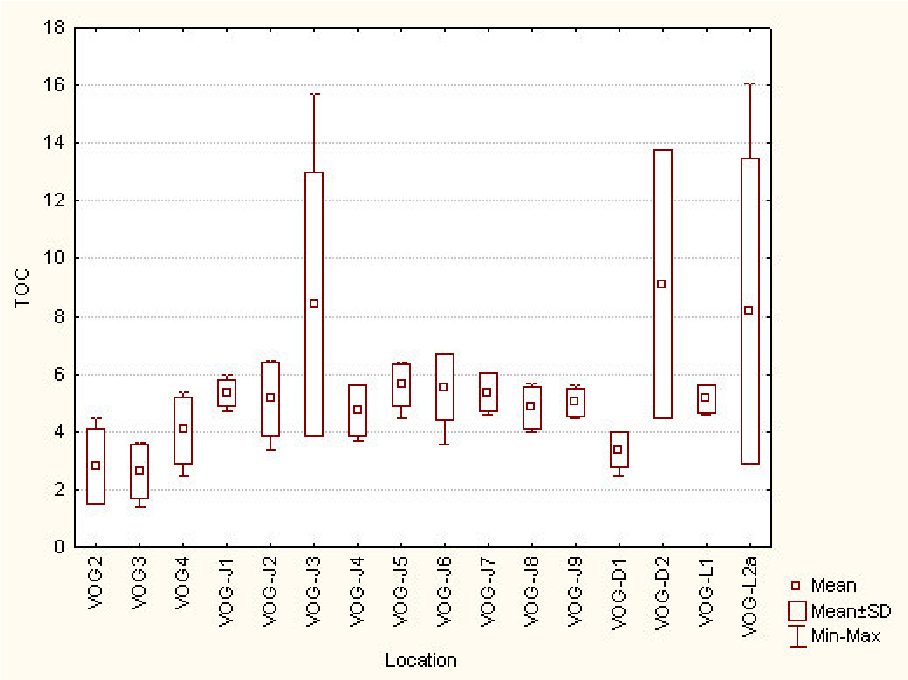


***Figure 6.4: TOC level range at single locations with marked minimum, maximum and mean value***

We found COD, $BOD_5$ and TOC levels recorded during our study at the upper and main basin to be in general higher than level for the respective variables cited in other water monitoring reports (ARSO, 2007, 2008, 2009, 2010; Monitoring površinskih voda..., 2007, 2008, 2009, 2010, 2011; Poročilo o preskusu, 2007, 2008, 2009, 2010). COD levels measured at the upper and main basin during our study ranged between 3.5 - 13 $mgl^{-1}$ *(Figure 5.19)*, with an average of 9.5 $mgl^{-1}$. In the cited reports measured COD levels at the upper and main basin showed a range between

1.7 – 8.8 $mgl^{-1}$, with an average level around 4 $mgl^{-1}$. $BOD_5$ levels at upper and main basin measured at our study ranged between < 2 – 5.9 $mgl^{-1}$, with an average of 3.1 $mgl^{-1}$ *(Figure 5.20)*, while $BOD_5$ levels at the upper and main basin in cited reports ranged between < 1 – 2.2 $mgl^{-1}$, with an average of 1.7 $mgl^{-1}$. We found COD and $BOD_5$ values recorded at the inflows similar to those reported by Luznik and Vrhovšek (1992), with a range between 3 – 11 $mgl^{-1}$ for COD and between 2 – 8 $mgl^{-1}$ for $BOD_5$. Although the reported levels occasionally differ from our measurements, the differences are not considerable. In both studies the levels were higher in summer and autumn, which can be explained with high activity period of living organisms in summer and the period of senescence and decay before winter. The only exception is the inflow VOG-L2a at which maximum COD value was recorded in our study (22 $mgl^{-1}$) and was almost two times higher than those recorded in autumn by Luznik and Vrhovšek (1992), while the respective $BOD_5$ value was consistent. Based on presented results we can sustain that the amount of organic matter present in the monitored inflows did not change significantly in 20 year period, while the amount of organic matter in the Vogršček reservoir, especially in the upper basin, shows a tendency to increase. This could be due to constant inflow of organic matter loads into the upper basin and to processes of decomposition and decay at the reservoir bottom as a consequence of the huge amount of inundated vegetation. We believe the latest affects the DO dynamics within the reservoir seriously and should be investigated.

Similarly to DO measurements we compared the results obtained in our study with the COD, BOD and TOC levels measured at the two Slovenian natural alpine lakes and the two Slovenian reservoirs. The two natural lakes exhibited lower COD levels < 2.1 $mgl^{-1}$ and TOC levels < 2.37 $mgl^{-1}$, compared to respective levels measured in our study where COD average was 9.5 $mgl^{-1}$ and TOC ranged between 4.7 – 5.6 $mgl^{-1}$ *(Figure 5.21)*. The Šmartinsko jezero reservoir showed COD levels very similar to the levels measured at upper and main basin in our study, while COD levels at the Velenjsko jezero reservoir were higher and consistent with the maximum COD value (22 $mgl^{-1}$) recorded in our study at VOG-L2a location. The TOC levels at the two reservoirs did not differ considerably from the levels measured at upper and main basin during our study. We emphasize that such comparisons are relative and serve just to get information about the water quality variables and ecological state of lakes and reservoirs in Slovenia versus the data obtained in our study. These comparisons do not take in account hydrologic, morphologic and other specific characteristics that condition the reservoir response against 'external impacts'.

A great amount of research has been conducted about surface water organic pollution due to untreated industrial and sewage wastewaters being discharged in lakes and rivers (e.g. Vulgaropoulos et al., 1987; Afzal, et al., 2000; Fall et al., 2007). To determine the sources, extend, and pollution effects COD, BOD and TOC measurements are fundamental. Studies report that COD in heavily polluted surface waters reached levels above 300 $mgl^{-1}$, and the highest BOD and TOC levels measured were around 200 $mgl^{-1}$. In the search for a tool able to ensure a long-term efficient water quality monitoring Wang et al. (2004) studied the possibility of determining water quality variables, such as COD, BOD and TOC, employing a remote sensor. The sensor was used to detect changes in water quality variables in five large reservoirs of Shenzen (China). This method needs a little ground proof and could be very useful to perform a constant water quality monitoring of vast areas.

In literature organic pollution of surface waters appears to be a serious problem especially in developing countries and the consequences for ecosystems and humans have proved to be severe (Afzal et al., 2000; Scheren et al., 2000). In these countries surface waters are widely used for drinking and irrigation water storage, food supply, agriculture, tourism, etc., and livelihood of communities and whole regions depends on water quality of these water bodies. Facing the gravity of the problem lots of studies and projects have been introduced to improve water quality and assure a proper management of endangered water bodies in these countries. Here we mention the case of Lake Victoria afflicted by a severe pollution the Governments of Kenya, Uganda and Tanzania cooperated and introduced the Lake Victoria Environmental Management Project (LVEMP) (Machiwa, 2003). LVEMP is a program to rehabilitate the Lake Victoria ecosystem through restoration and conservation of biodiversity in the lake and within the catchment area. Rarely the Governments of these three countries found a way to collaborate as it happened in this case. Another example is a study performed by Yang and Liu (2010) at Taihu Lake in China. The authors suggest that the best solution to remediate water-related threats (pollution, flooding and water shortages) at Taihu Lake would be to build a by-pass channel to divert low quality water from the lake during low precipitation periods and allow better quality water to flow into the lake during high flow periods.

### *6.1.5 Nitrogen and phosphorous*

Among sampling locations the stream inflows VOG-D1, VOG2 and VOG3 exhibited the highest $NO_3$-N values, with respective maximums of 1.51 mgl$^{-1}$, 1.42 mgl$^{-1}$, and 1.35 mgl$^{-1}$ *(Figure 5.22).* $NO_3$-N values were in general higher also at the melioration ditches compared to other sampling locations, with the average ranging between 0.62 to 0.83 mgl$^{-1}$ and a peak of 1.51 mgl$^{-1}$ recorded at VOG-L1 in April. $NO_3$-N concentrations recorded at upper and main basin exhibited an average range between 0.45 – 0.61 mgl$^{-1}$. Figure 6.5 shows $NO_3$-N concentrations range, with minimum, maximum and mean value at single sampling locations; high variability in $NO_3$-N concentrations at stream inflows and melioration ditches can be observed.

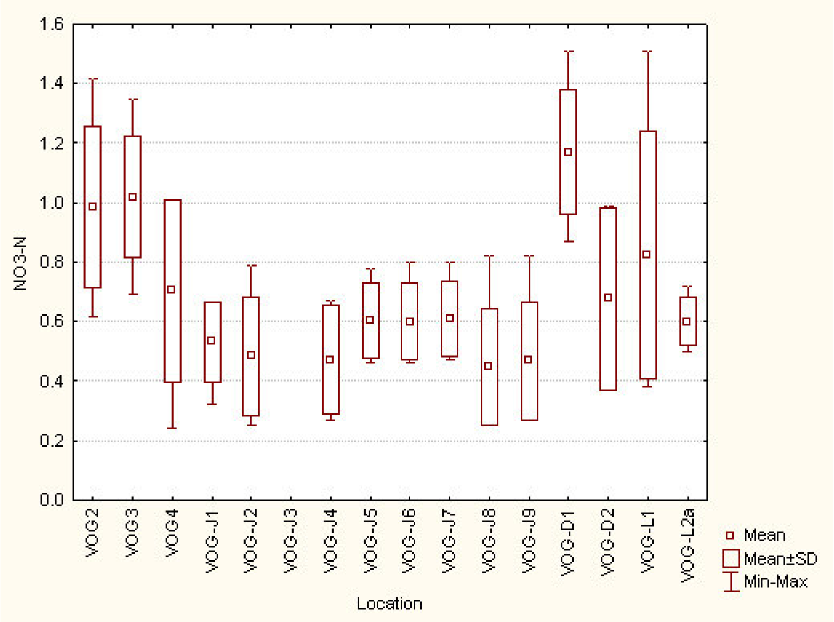


***Figure 6.5: $NO_3$-N concentration range at single locations with marked minimum, maximum and mean value***

The $NO_3$-N concentrations at the two basins of Vogršč𝑒k reservoir recorded in other water quality reports (ARSO, 2007, 2008, 2009, 2010; Monitoring površinskih voda…, 2007, 2008, 2009, 2010, 2011; Poročilo o preskusu, 2007, 2008, 2009, 2010) are consistent with our range of values (< 0.8 $mgl^{-1}$); taken in account that the sampling dates were not the same. While $NO_3$-N concentrations recorded at our study are considerably higher than those reported by Luznik and Vrhovšek in 1992. The $NO_3$-N maximum reported by Luznik and Vrhovšek (1992) was 0.65 $mgl^{-1}$ at the inflows, and the upper basin was 0.2 $mgl^{-1}$. In general, $NO_3$-N concentrations cited in their study are about two times lower at the inflows and three to four times lower at the upper basin compared to measurements reported in our study. Luznik and Vrhovšek (1992) in their study concluded that the recorded $NO_3$-N concentration levels exhibit an impact of human activities on the inflows and the reservoir Vogršč𝑒k. Based on this comparison we are able to say that $NO_3$-N concentrations at the Vogršč𝑒k reservoir and its inflows increased considerably in the 20 years period. The results are consistent with the DO and COD and $BOD_5$ data discussed above; since 1992 DO decreased and other respective variables increased. Considering these observations we believe the ecological state of the Vogršč𝑒k reservoir and its drainage area is likely to aggravate, if a proper mitigation approach is not established.

$NO_3$-N concentrations at the stream inflows VOG2, VOG3 and VOG-D1 were higher than at other sampling locations at all the measurements performed. The highest concentrations at these locations were recorded in summer. The latest might be due to reduced dilution of discharged domestic wastewaters because of low precipitation in summer. In spring and autumn the $NO_3$-N concentrations were relatively higher also at melioration ditches VOG-D2, VOG-L1 and VOG-L2a beside stream inflows. In our opinion this could be attributed to higher precipitation in spring and autumn and consequently increased agricultural surface run-off. Agricultural surface run-off is also the reason for persistence of relatively higher $NO_3$-N concentrations at the stream inflows although the dilution of discharged wastewaters increased in spring and autumn. Similarly to melioration ditches, $NO_3$-N concentrations at the upper and main basin showed a noticeable decrease in summer compared to spring and autumn *(Figure 5.22)*. According to Twort et al. (2000) nitrate levels in surface waters often show marked seasonal fluctuations, with likely reduced nitrate levels in reservoirs during summer biochemical mechanisms and by algal assimilation and higher concentrations occurring in colder period of the year, when runoff increases due to winter rains at a time of reduced biological activity. In Luznik and Vrhovšek (1992) report nitrate values were the highest in spring at the inflows, and at the upper and main basin in autumn. Their nitrate concentration pattern is quite consistent with the pattern recorded in our study. With one exception, in that the highest nitrate concentrations at the inflows were recorded by Luznik and Vrhovšek (1992) in spring, while in our study the highest nitrate concentrations at the stream inflows were recorded in summer. The reason could be partially attributed to differences in sampling locations, since the points examined were not exactly the same, and partially maybe to the difference in precipitation pattern and surface run-off between year 1991 and 2010. However, the spring peaks at the inflows were not further discussed by Luznik and Vrhovšek (1992) and no explanation was suggested.

We are not able to compare the obtained phosphorous concentration data with the values recorded in other reports, since $PO_4^{3-}$ measurements were below LOD (< 1 $mgl^{-1}$) for all the samples tested. This suggests ion chromatography was not a suitable method for $PO_4^{3-}$ determination. Consequently we limit the discussion to $NO_3$-N values. In comparison with other Slovenian monitored water bodies the maximum $NO_3$-N concentrations at the inflows of alpine lake Bled were quite similar to Vogrščcek inflows concentrations (1.52 and 1.65 $mgl^{-1}$), while the maximum lake (epilimnium) values were lower (0.2 – 0.4 $mgl^{-1}$). Lake Bled was confirmed to show signs of severe eutrophication in past years (ARSO, 2008, 2009, 2010). In the case of comparison between alpine lake Bohinj, which was assessed to be in a 'ecologically good state', and our study area, concentrations were lower at the Bohinj lake inflow, with a maximum of 0.82 $mgl^{-1}$, and in the lake epilimnium, with a maximum of 0.44 $mgl^{-1}$ (ARSO, 2008, 2009, 2010). Data of $NO_3$-N values recorded at other Slovenian reservoirs, which were assessed to be eutrophic in 2008 and 2009 (ARSO, 2009, 2010), varied within a range of 0.7 – 4.6 $mgl^{-1}$.

According to Chapman and Kimstach (1998) natural concentrations of $NO_3$-N seldom exceed 0.1 $mgl^{-1}$. When influenced by human activities, such as municipal and industrial wastewaters discharge, leaching from waste disposal sites, and leaching of inorganic fertilizers and organic manure from agricultural land via drainage point discharges or diffuse runoff, surface waters can have concentrations up to 5 $mgl^{-1}$ $NO_3$-N, but often less than 1 $mgl^{-1}$ $NO_3$-N (Chapman and Kimstach, 1998). In lakes, concentrations of nitrate in excess of 0,2 $mgl^{-1}$ $NO_3$-N tend to stimulate algal growth and indicate possible eutrophic conditions (Chapman and Kimstach, 1998). On the other hand Wetzel (2001, p. 213) suggests that concentrations of $NO_3$-N range from undetectable levels to nearly 10 $mgl^{-1}$ in unpolluted fresh waters worldwide but emphasizes that are highly variable seasonally and spatially.

In order to get a better insight into eutrophication as a consequence of anthropogenic impact on surface water bodies we examined several studies. Some of these studies were already mentioned in previous discussion chapters (Soltero et al., 1973; Saad et al., 1984; Kotut et al., 1999; Karakoς et al., 2002; Gunes, 2008), since interconnected water quality variables (DO, COD, BOD, $NO_3$-N, etc.) are usually studied together. According to literature the number of surface water bodies that have undergone 'human induced eutrophication' all over the world is immense and such is the number of studies linked to this processes and efforts to mitigate them. Here we point out some of the most important information in relation to anthropogenic induced eutrophication:

- the most important nutrient factors causing the shift from a lesser to a more productive state are phosphorous and nitrogen (Robards et al., 1994; Holas et al., 1999; Wetzel, 2001; Kondratyev et al., 2002),
- nutrient emissions from agricultural land and urban sources have proved to be a major cause of elevated nutrient concentrations in surface and ground waters (Soltero et al., 1973; Saad et al., 1984; Reisenhofer et al., 1994; Holas et al., 1999; Kotut et al., 1999; Scheren et al., 2000; Wetzel, 2001; Karakoς et al., 2002; Kondratyev et al., 2002; Withers and Lord, 2002; Gunes, 2008),
- individual water bodies differ greatly in their sensitivity and response to nutrient inputs and the best way of defining the conditions under which agriculture has a significant impact is to relate their nutrient and ecological status to the landscape in which they reside (Edwards et al., 2000; Wetzel, 2001),
- although phosphorous is likely to be the limiting nutrient and more important in water bodies impacted by agriculture, nitrate–N ($NO_3$-N) is of much greater concern, because it renders water unsuitable for drinking, and because as phosphorous loading to fresh waters increases and lakes become more productive, nitrogen often becomes nutrient limiting (Wetzel, 2001; Withers and Lord, 2002; Howden et al., 2009).

There has been a major effort in European Countries in recent decades to determine nutrient concentrations and fluxes from agricultural areas and their impact on surface waters, in order to find a land use and land management scenarios that would reduce nutrient loads. The effort was employed largely due to meet the main objective of European WFD, which is the achievement of a good ecological and chemical status of the water environment (water bodies) (Withers and Lord, 2002; Schröder et al., 2004; Neal et al., 2008; Howden et al., 2009; Volk et al., 2009). A central water quality issue is the impact of nitrogen (nitrate-N) and phosphorous (phosphate-P) on eutrophication, both of which derive primary from sewage and agricultural sources (Withers and Lord, 2002; Howden et al., 2009). In relation to agricultural sources the main issue, is the control of non-point sources of pollution or diffuse pollution from agricultural landscapes (Howden et al., 2009; Volk et al., 2009). Diffuse pollution varies considerably as a complex function of soil type, climate, topography, hydrology, land use, and management (Withers and Lord, 2002; Schröder et al., 2004; Howden et al., 2009).

As these studies have demonstrated, policy strategies towards maintaining 'good' water quality must be based on a sound understanding of the processes of nutrient transfer from agricultural land at terrain and river basin scale and they should include long term monitoring of such agriculturally-impacted water systems and cost effective methods of control to reduce emissions to acceptable levels (Withers and Lord, 2002; Howden et al., 2009). An important fact was also pointed out by Withers and Lord (2002), i.e., since farmers have to work within the landscape resources, which are at their disposal, it is important that the relative risk of N and P loss is quantified at the field scale in order that they can be advised on the most desirable management practices to minimize nutrient loss, and of the consequences of deviating from safe management practices. However, these practices should differentiate; as there are different situations within European Countries and even regions, since serious local and regional constraints can be imposed by soil, climate, topography, geology, etc. (Schröder et al., 2004). Regarding agricultural pollution sources is proper to mention a critical review performed by Stevens and Quinton (2009). Their review pointed out that pollution swapping is a point of concern when trying to mitigate pollution, and stated that although pollution swapping is widely understood, it has received little attention in research and policy design. They investigated pollution swapping in combination with diffuse pollution mitigation options applied in combinable crop systems. The investigated mitigation options were cover crops, residue management, no-tillage, riparian buffer zones, contour grass strips, and constructed wetlands. They tended to demonstrate the effect of mitigation options on different pollutants. They concluded that because of opposing impacts that different mitigation options have on pollutants, it is not possible to recommend a single strategy for reducing diffuse pollution. Pollution swapping should be considered when selecting a mitigation option, and the most appropriate option should be selected on a site-by-site basis. They also reminded to consider maintenance costs when choosing mitigation options, since poorly maintained mitigation options can become a source of pollutants rather than a sink.

## 6.2 Toxicity

Worldwide and in Slovenia as well, water quality monitoring is generally based on monitoring of physical, chemical and microbiological variables within the water bodies. These however, do not provide information about possible dangerous biological effects of eventually present pollutants on living organisms (Farré et al., 2005; Marinšek et al, 2006). Due to extensively increasing number of unknown pollutants and the difficulty of predicting their collective effects on receiving ecosystems, there is a need in environmental monitoring for screening methods (Farré et al., 2005; Girotti et al., 2008). Based on speed and cost considerations a bioluminescence (BL) inhibition assay is often chosen as the first screening method in a test battery (Girotti et al., 2008). According to the review of Girotti et al. (2008) researches have reported the bioluminescence assay based on *Vibrio fisheri* to be the first and most employed luminescent strain, as the most sensitive across a wide range of chemicals, and shows a good correlation to other toxicity bioassays like those on algae, crustacean, fishes, etc. Therefore, bioluminescent bacteria although very sensitive to pollutants, have been widely used for wastewaters toxicity monitoring, especially for determining ecotoxicological effects of wastewater-treatment-plants effluents (Katsoyiannis and Samara, 2007; Bayo et. al, 2009) and the effectiveness of different wastewater (industrial and sewage) treatment technologies (Sütterlin et al., 2008; Lundström et al., 2010). Beside water testing, the method is employed also for ecotoxicological screening of sediments and soils, since nowadays the control of sediment quality is being considered as a necessary extension of water quality monitoring (Borja et al., 2004, cited in: Ocampo-Duque et al., 2008). However, the identity of potential problematic pollutants can not be revealed by biotests, because they only provide information about general toxicity of the tested sample (Girotti et al., 2008); therefore, further analyses would be needed to determine the problematic elements.

The results of bioluminescent bacteria *Vibrio fisheri* tests performed with samples taken at Vogrščžek reservoir and its inflows varied considerably within locations, among locations, and seasonally and exhibited no constant pattern. The inhibition percentage was >20 % on five occasions, twice at the wetland-1, once at wetland-2, and twice at the upper basin (VOG-J5, VOG-J6). The results suggest possible toxicological effects of water on living organisms at appointed locations on the date of sampling. To determine the effective concentrations, acute toxicity and the identity of toxic pollutants was beyond the purpose of our study, since the samples should be subjected to further analyses. In all other tested samples the inhibition percentage was reduced to <20 % and they were considered as non-toxic according to Girotti et al. (2008). However, as suggested by Katsoyiannis and Samara (2007) samples that inhibit bacterial luminescence by more than 15 % should be subsequently tested to quantify their acute toxicity, which would in our case include at least four other locations *(*see chapter 5.14*; Figure 5.23)*. Based on the discussed results we suggest performing more detailed ecotoxicological tests at the Vogršček reservoir and its inflows in the future.

According to Wong et al. (1995), as reported by Katsoyiannis and Samara (2007), the results of the sampling performed on 11th of August at which bioluminescence inhibition dropped to negative values in all samples except one, these indicate stimulation of bacteria, meaning the actual water conditions stimulated and not inhibited bacterial activity.

## 6.3 Wetlands

A lot of studies and works have been published in the last three decades about the productive capacities of wetlands and littoral flora of surface waters, the heterogeneity of these plant communities, and their general ecology. In particular, much interest exists in the potential capacities of the wetlands and littoral macrophyte-algal complex to inhibit or reduce nutrient loading from the drainage basin to the recipient lake, river or stream, i.e. to function as a nutrient sink (Wetzel and Corners, 1979; Wetzel, 1989; Wetzel, 1990a; Fennessy and Cronk, 1997; Wetzel, 2001; Pepper et al., 2006; Hillbricht-Ilkowska, 2008). Riparian wetlands and littoral flora function as ecotones, mediating the flux of water, energy, sediment and other materials across the landscape and altering the quality of recipient surface water (Fennessy and Cronk, 1997). As water of the drainage basin containing inorganic nutrients and organic compounds, passes through the complex vegetation formed by macrophytes and their epiphytes (attached microflora), they can be extremely affective in removing nutrients, e.g. Ca, K, combined N, P, of inflowing water. Nutrients loaded to the zone of emergent macrophytes tend to be assimilated by microflora (primarily bacteria) of the sediments and macrophytic detrital particles, and recycled to the emergent macrophytes from the sediments and associated detritus (Wetzel, 1990a; Wetzel, 2001). Beside 'the sink' function, wetlands and littoral communities also function as nutrient sources, particularly resulting from the autolysis and decomposition of plant organic matter. During senescence and decay of macrophytes the release of ions (nutrients) may be into the water or to the sediment (Wetzel, 2001). However, as Wetzel (1990a, 2001) suggests according to several studies in both cases (sink and source function) the attached microbial community is the main actor in this processes and the first to sequester most of the nutrients being released.

Two major natural wetlands have formed naturally at the northern margin of the upper basin Vogršček reservoir *(Figure 3.5)*. Maximum width of wetland-1 is about 30 m, and wetland-2 about 15 m. For the purpose of our study samples were taken at both wetland areas (chapter 3.5; *Figure 3.5*). When compared to other sampling locations, wetland locations differ in almost all variables measured, i.e.:

- average pH was lower at wetland locations compared to all locations, except for melioration ditches,
- EC at wetland locations showed two variations in autumn – an evidently higher EC value at wetland-1 in September and an evidently lower EC value at wetland-2 in October *(Figure 5.4)*; for the rest of the measurements EC values at the wetlands were consistent with other upper and main basin locations,
- ion concentrations at wetland locations showed some significant variations only occasionally,
- DO levels were lower at wetlands compared to the upper basin,
- COD, $BOD_5$, and TOC levels at wetlands were higher compared to the upper basin and were more similar to levels recorded at melioration ditches; the most significant variations were recorded at wetland-1 (VOG-J3),
- $NO_3$-N levels at wetlands were significantly lower compared to the inflows and compared to those of the main basin, especially during summer months.

In general, wetland locations differed from other locations and among themselves, and showed variable and inconstant patterns. Although we focus our further discussion on the nutrient, especially nitrate-nitrogen ($NO_3$-N) removal by the aid of wetlands, it is important to acknowledge the overall beneficial function of wetlands, which includes mediation of water flux, sediment loads, energy, particulate and dissolved organic matter.

Numerous studies cited in Fennessy and Cronk review (1997) have discussed the removal of nitrate nitrogen ($NO_3$-N) from surface and subsurface agricultural runoff within riparian areas, by two mechanisms – the first is plant incorporation, and second is denitrification. The final product of denitrification is the release of dinitrogen gas ($N_2$), which represents a permanent loss of nitrogen from the system. However, in both processes (incorporation and denitrification) plant communities play an important role:

- their physical presence promotes sedimentation and prevents erosion,
- they take up nutrients, bind them in their biomass and free exchange sites in the soil,
- litter provides habitat for microbe colonization and along with root exudates is the primary source of organic carbon used in denitrification (Fennessy and Cronk, 1997).

Studies suggest that denitrification process depends largely upon the amount of $NO_3$-N and organic carbon, dissolved oxygen, pH, temperature, and the denitrifying bacteria (Li et al., 2008). Reviewed studies (Fennessy and Cronk, 1997) have showed that:

- denitrification occurs primarily at the soil-water interface or within the soil; not depended on the presence of water column;
- more nitrogen tends to be lost when both aerobic and anaerobic conditions are present;
- regarding to sediment composition and texture, higher rate of $NO_3^-$ was denitrified within a poorly drained calcareous clay loam in comparison to other sediments,
- low temperature and acidic soil condition tend to inhibit denitrification.

Considering these statements the Vogršček upper basin wetland locations show characteristics, such as average pH of 7.3, water temperature up to 29 °C during summer time, alternating oxygen conditions (DO levels varied from 1.5 to 6 $mgl^{-1}$), and base consisting of clay and mud sediment, which indicate a potential for denitrification to occur along with nitrate removal by plant incorporation. These observations suggest that wetlands formed at the Vogršček upper basin have the capacity to buffer external nutrient and other loads that enter into the upper basin with the inflows (chapter 6.1.5). However, to determine weather the wetlands do actually carry out this capacity, acting like a kind of upper basin buffering zone, and up to which amount, more detailed studies should be performed in the future.

Mwanuzi et al. (2003) presented a wetland model, used to study the buffering capacity of natural wetlands fringing Victoria lake. The main objective of the model was to establish and simulate the buffering processes and capacity of individual wetlands, their ability to absorb sediments, nutrients and pollutants. Authors based their conclusions on the good model overlap with the measured values on both hydrodynamics and water quality variables, and thus confirmed that the model can be applied to study the buffering capacity of the wetlands. We believe a similar study should be performed in order to understand how the wetlands function within the upper basin in the Vogršček ecosystem, and to assess possible removal of nutrient loads. It has been widely recognized that natural and constructed wetlands (if properly kept) with their pollution mitigation capacity represent a great instrument for recipient water body ecosystem protection.

Kovacic et al. (2006) studied the effectiveness of two agricultural runoff constructed wetlands intercepting surface and tile drainage in the Lake Bloomington watershed, Illinois (USA). They found $NO_3$-N concentrations reduced up to 42 %, combined P mass retention was 53 %, and combined TOC mass retention was 9 %. In the case of Lake Kasumigaura in Japan (Nakamura, 2009) they report about performance and design of artificial lagoons for controlling diffuse pollution. The artificial lagoon ('lagoon inside a lake') is a water treatment 'device' consisting of a small body of water enclosed by banks and constructed at the mouth of a river flowing into the lake. It functions as habitat and controls non-point pollutants over the whole river basin. The lagoon put up is usually followed by ecological enhancements through the creation of a calm, shallow pond or wetland. In Lake Kasumigaura four artificial lagoons have been installed at the mouths of inflowing rivers. The rates of removal ranged from 8.2 % to 44 % for COD, from 0.9 % to 8.7 % for TN, and from 9 % to 55 % for TP (Nakamura, 2009). In our opinion an artificial lagoon is an option that should be studied in the context of possibilities for the mitigation of the impact of inflowing loads on Vogrščck upper basin. The embayment in which the VOG4 sampling site (described in chapter 6.1.1) was placed could be a potentially suitable location to place an artificial lagoon.

Some additional studies caught our attention because they report about accelerated extensive growth of cattail *(Typha sp.)*. Authors suggest that elevated nutrient concentrations in natural Evergaldes wetlands area in Florida, and in constructed wetlands at Lake Taihu in China influenced the growth of cattail *(Typha sp.)* (Newman et al., 1998; Li et al., 2008). We think this observation should be considered in possible further studies at the area of Vogrščck upper basin wetlands, since both wetlands at the upper basin consist of dense cattail vegetation (chapter 3.5).

We conclude this chapter reminding that, beside the two wetlands at the north-eastern margin of the upper basin, at some of our sampling locations the water body is divided from adjacent cultivated crops and vineyards by a riparian forest belt; e.g. the upper basin (VOG-J9) location, the inner edge of wetland-1 (VOG-J3), and the embayment at VOG4 location (*Figure 3.4*; chapter 3.5). According to Fennessy and Cronk (1997) forested buffer stripes were very efficient in removing nitrate in all flow conditions (surface and sub-surface flow). We believe that the riparian forest zones mitigate diffuse pollution sources that gravitate towards Vogrščck reservoir from surrounding agricultural area as run-offs. However, this is another suggestion yet to be proved by further detailed research which should focus on the buffering capacity of forested riparian areas at the northern agricultural area of Vogrščck reservoir.

# 7 CONCLUSIONS

Inland waters are exposed to numerous natural and anthropogenic stress factors. The increased impact of human activities on the aquatic environment during the past centuries is resulting in the degradation of many aquatic ecosystems. Threats to water quality do not only derive from the populated areas and cultivation, but also from use of inland waters and their respective catchments for different purposes.

In our study we aimed to determine a possible impact of anthropogenic activities within the drainage area of the Vogršček reservoir on water quality of the upper basin and its inflows. We also wanted to get information about possible buffering capacity of two major natural wetlands that have developed at the north-eastern marginal part of the upper basin. By comparison of data recorded in our study with data recorded in previous studies we tried to determine a possible trend of measured water quality variables in twenty years period.
We have formatted the following hypothesis:

- anthropogenic activities within the Vogršček reservoir drainage area, such as domestic wastewater discharges and agricultural activities, affect the water quality of the upper basin and its inflows,
- natural wetlands at the north-eastern marginal part of the upper basin have the capacity to mitigate the impacts of the upper basin inflows and act as a buffering zone between the inflowing loads and the upper basin.

The results confirmed a difference in measured physical and chemical variables according to different locations. The inflows, wetlands, upper basin, and main basin showed different patterns for almost all variables measured. The following was concluded:

- Melioration ditches exhibited the highest EC values, with a range between 317 – 691 µScm$^{-1}$ and the highest concentrations of the measured major ions. At the melioration ditches, as well as at all monitored locations, $Ca^{2+}$ concentrations were fairly higher compared to other measured major ions. This is consistent with the fact that $Ca^{2+}$ is highly present in sediment rocks within the Vogršček drainage basin area, since major ions concentrations are very variable due to local geological, climatic and geographical conditions. For this reason a further research (i.e. isotope analyses) should be performed to determine a natural occurrence or possible anthropogenic origin of measured major ions. Linear correlation results suggest that $Ca^{2+}$ had the strongest influence on EC values, which is again consistent with $Ca^{2+}$ being highly present in sediment rocks within the Vogršček drainage basin area. Melioration ditches exhibited the lowest DO levels, with a minimum of 0.5 mgl$^{-1}$ in summer and a maximum of 8.2 mgl$^{-1}$ in late autumn, and the highest levels for all three variables COD, $BOD_5$ and TOC, with respective maximums of 22 mgl$^{-1}$ (COD), >7 mgl$^{-1}$ ($BOD_5$) and 16,08 mgl$^{-1}$ (TOC). We believe melioration ditches represent potential locations of organic matter overload. The $NO_3$-N concentrations at the melioration ditches were relatively higher compared to upper and main basin locations, with the average ranging between 0.62 to 0.83 mgl$^{-1}$, but lower compared to $NO_3$-N concentrations recorded at the stream inflows;

- Stream inflows exhibited higher and more variable EC values compared to the upper and main basin, with values ranging between 328 – 440 µScm$^{-1}$. Higher EC values at melioration ditches and stream inflows could be attributed to surface runoff from the drainage area and surrounding cultivated land. Because of higher EC values and their variability we suggest future water quality monitoring measurements to focus on reservoir inflows (major streams and melioration ditches). A future study should include flow measurements, TDS measurements, isotope analyses, heavy metals analyses, pesticide analyses and microbiological analyses, which were not performed at this study. DO levels were higher at the stream inflows compared to other locations, ranging between 7.4 mgl$^{-1}$ and 9.53 mgl$^{-1}$, with a saturation range of 72.9 to 90.9 %. Consistently, the stream inflows exhibited the lowest COD, $BOD_5$ and TOC levels, ranging between 3 and 6.4 mgl$^{-1}$ (COD), < 3 mgl$^{-1}$ ($BOD_5$) and 2.6 – 3.4 mgl$^{-1}$ (TOC). One stream inflow location (VOG4) showed values more consistent with upper basin locations than with other stream inflows locations. This suggests that VOG4 location was actually placed within an upper basin embayment and not in the closer area of stream inflow into the upper basin. Among monitored locations the stream inflows showed the highest $NO_3$-N concentrations, with a range between 0.7 and 1.17 mgl$^{-1}$, and a maximum of 1.51 mgl$^{-1}$. In general $NO_3$-N concentrations recorded in our study were considerably higher, when compared to concentrations recorded in previous study. Concentrations of $NO_3$-N at the inflows and consequently at the upper basin seem to have increased in the period of 20 years. The resulting pattern of $NO_3$-N concentrations at the inflows and upper basin demonstrates signs of anthropogenic impact on $NO_3$-N concentrations. These suggest a tendency toward aggravation of water quality at the upper basin and its inflows; however, further analyses (e.g. isotope analyses) are needed to prove this statement;
- At the upper basin EC values ranged from 251 to 420 µScm$^{-1}$. EC values recorded at upper basin were higher than those recorded at main basin, which is probably due to the impact of inflows on the upper basin. DO levels at the upper and main basin did not vary considerably, with a minimum and maximum of 5.02 mgl$^{-1}$ and 8.8 mgl$^{-1}$ and a saturation level between 49.6 and 109 % at both basins. However, the results showed a trend toward a general decrease in DO levels within the area of study. If not taken care of, DO deficiency might represent a serious problem at Vogršček reservoir in the future. In order to be able to ensure a proper management of the reservoir and a healthy aquatic ecosystem, oxygen conditions and oxygen dynamics within the reservoir should be accurately studied. COD, $BOD_5$ and TOC levels at the upper and main basin were consistent and ranged between 3.5 - 13 mgl$^{-1}$ (COD), < 2 – 5.9 mgl$^{-1}$ ($BOD_5$), and 4.7 - 5.6 mgl$^{-1}$ (TOC). The amount of organic matter in the upper basin shows a tendency to increase. This could be due to constant inflow of organic matter loads into the upper basin and to processes of decomposition and decay at the reservoir bottom as a consequence of the huge amount of

inundated vegetation. We believe the latest affects the DO dynamics within the reservoir seriously and should be investigated. At the upper basin $NO_3$-N values exhibited an average between 0.47 – 0.61 $mgl^{-1}$, while average $NO_3$-N values at the main basin ranged between 0.45 – 0.49 $mgl^{-1}$. As mentioned, based on the results obtained, concentrations of $NO_3$-N at the inflows and consequently at the upper basin have increased in the period of 20 years, which suggests a tendency toward aggravation of water quality at the upper basin and its inflows;

- The results of measured variables at wetlands were not consistent with any other monitored location and showed variable and inconstant patterns. EC values at wetlands were in general consistent with those recorded at the upper basin locations, except for two considerable variations in September and October at both wetland locations. The major cations concentrations were higher at wetland-1, compared to all other upper and main basin locations, while the anions concentrations were the lowest at wetland-1. The DO levels recorded at the wetlands were lower and consistent with those measured at melioration ditches, with an average saturation level of 31.8 % at the wetland-1, and an average saturation level of 57.8 % at other wetlands locations. However, we attributed lower DO levels at wetlands and melioration ditches in major part to lack of precipitation and higher evaporation losses during the warm period of the year. COD, $BOD_5$, and TOC levels recorded at wetlands were relatively higher and, like DO levels, closer to levels measured at melioration ditches, with a range between 9.5 – 13.2 $mgl^{-1}$ (COD), > 5 $mgl^{-1}$ ($BOD_5$) and 3.38 – 15.73 $mgl^{-1}$ (TOC). Based on the results we concluded that beside melioration ditches wetlands also represent the potential locations of organic matter overload. $NO_3$-N values at wetlands locations were lower compared to stream inflows and melioration ditches, and were consistent with upper basin values. These results suggest there is difference in processes that occur within the wetlands influential area and outside. We believe that two major wetlands at the Vogršček upper basin have the capacity to buffer external impacts on the upper basin; but, to determine, if the wetlands do actually carry out this capacity and up to what amount, more detailed studies are needed;
- The results of ecotoxicological analyses confirmed the presence of possible toxic elements on few occasions at the wetlands and at the upper basin. This suggests possible toxicological effects of water on living organisms at appointed locations on the date of sampling. To determine the effective concentrations, acute toxicity and the identity of toxic pollutants the samples should be subjected to further analyses;
- $PO_4^{3-}$ concentrations were below 1 $mgl^{-1}$ (LOD) at every measurement. We sustain that ion chromatography was not a suitable method for $PO_4^{3-}$ determination. For a proper comparison with $NO_3$-N concentrations more accurate data about $PO_4^{3-}$ would be needed.

Three contemporary water quality monitorings are being carried out at the upper and main basin of Vogršček reservoir since 2006, supported by different competent services. Numerous analyses are being performed which require a considerable financial support. Despite three reports issued every year containing all the monitored data, these are not substantively connected; neither any monitoring of the reservoir drainage basin area and its inflows is included. An overwhelming amount of data is obtained but not handled and presented in the way to understand the processes within the reservoir ecosystem. In our opinion the water quality monitoring performed at the Vogršček reservoir at present time is orientated in ' data collection' according to current Slovenian and European legislation, but not in understanding the limnological characteristics of the reservoir and its drainage basin.

Vogršček represents a specific case among the reservoirs. The division of the reservoir water body on upper and main basin makes Vogršček a rarity among reservoirs. Each of the basins has its own characteristics; because the withdrawal activity is only performed at the main basin, the upper basin shows many characteristics typical for a natural lake, e.g. preserved littoral vegetation and the lack of abnormal water level fluctuations. The Vogršček reservoir offers great amount of challenges and opportunities for ecologists and limnologists to study and learn about aquatic ecosystems. However, despite few attempts to perform a detailed and integrated study about the Vogršček reservoir ecosystem, none was completed. We believe, when designing a water quality monitoring programme, the aim of the facility operator and manager should be to provide an effective management of the facility and ensure a healthy aquatic environment. This is only possible by knowing the origin, characteristics and dynamics of processes that occur within the reservoir water body and its drainage basin.

# 8 SUMMARY

Much of scientific limnological understanding originates from natural lake ecosystems. Since lakes and reservoirs are both lentic systems, they do share a lot of common attributes, but on the other hand, reservoirs differ in some significant ways from natural lake ecosystems. The basic difference that influences the reservoirs limnological characteristics and their response to external in internal impacts is in their anthropogenic origin.

Even though humans have created artificial lakes by damming streams and rivers for thousands of years, is only in the last two centuries that this activity has become significant for the purposes of flood control, generation of electrical energy and for water supply and irrigation. Reservoirs are being constructed on an unprecedented scale in response to the exponential demands of humans. Most of them are constructed without much concern that alterations of drainage systems may result in considerable changes in water quality of aquatic ecosystems. Surface waters, i.e. streams and rivers, at some point end in a recipient water body, weather lake, reservoir or ocean. Therefore, lakes and reservoirs are reflections of all natural and anthropogenic processes that have occurred in the watershed up to that point. If this 'drainage basin concept' is not taken in account when designing a reservoir, the deriving impacts can in the long term affect aquatic communities as well as human environment within the drainage area and even wider.

Although lakes and reservoirs are constantly exposed to numerous natural and anthropogenic stress factors, the anthropogenic impact is the one raising much more concern in the last decades. The increased impact of human activities on the aquatic environment during the past centuries is resulting in the degradation of many aquatic ecosystems. Threats to water quality do not only come from the populated areas and cultivation, but also from use of inland waters and their respective catchments for different purposes.

The aim of our study was to determine a possible impact of anthropogenic activities on water quality of the Vogršček reservoir. The Vogršček reservoir is situated in western Slovenia, in a rural area within the lower part of Vipava valley. The valley is named after its main watercourse, the Vipava River. The reservoir was built in late 80-ties by placing a barrier on the Vogršček stream, which is rivers right tributary. The main purpose of the reservoir is irrigation water supply and flood wave control. Before the reservoir was completed, a highway (HC Nova Gorica – Vipava) dam was built within the reservoir area, which divides the actual reservoir water body in two parts, the upper basin and the main basin. The upper basin is the recipient of the Vogršček stream and other inflows originating from the surrounding rural area, while the main basin serves as major water storage. Both basins were reported to show signs of eutrophication on several occasions in the past twenty years. The upper basin was of major concern, since it receives surface waters from surrounding areas which includes villages, single households, traffic connections, and agricultural run-offs. Our study was focused on the reservoir upper basin and its inflows. The aim was to determine a possible impact of anthropogenic activities within the reservoir recharge area, such as domestic wastewater discharges and agricultural practices, on upper basin and its stream inflows and on their water quality. Some of the melioration ditches that gravitate towards the reservoir upper basin and its stream inflows were also monitored as potential recipients of cultivated land run-offs. We aimed also to get information about the possible buffering capacity of two major wetlands which have developed at north-eastern margin of the upper basin. The obtained results were compared with the results from a previous study performed within the same area almost twenty years ago. On the basis of comparison we attempted to determine a possible trend of measured water quality variables at the upper basin and its inflows during the mentioned period of time.

Water quality monitoring included measurements of following variables: air and water temperature (T), pH, electrical conductivity (EC), dissolved oxygen (DO), dissolved oxygen saturation, chemical oxygen demand (COD), biochemical oxygen demand ($BOD_5$), total organic carbon (TOC), Calcium ($Ca^{2+}$), Magnesium ($Mg^{2+}$), Potassium ($K^+$), Ammonium ($NH_4^+$), Sodium ($Na^+$), Fluoride ($F^-$), Chloride ($Cl^-$), Bromide ($Br^-$), Nitrite ($NO_2^-$), Nitrate ($NO_3^-$), Sulphate ($SO_4^{2-}$), ortho-Phosphate ($PO_4^{3-}$) and toxicity. Field work, sampling and laboratory analyses followed the standard methods adopted for water quality monitoring and assessments. Sampling locations were selected by studying the reservoir recharge basin characteristics and by performing an accurate field survey. Measurements of water and air temperature (T), pH, EC, DO, and dissolved oxygen saturation were carried out *in situ* using the WTW (Wissenschaftlich-Technische-Werkstätlen, Weilheim, Germany) MultiLine P4 portable universal pocket-size meter. The determination of COD, $BOD_5$, and $NH_4^+$ was done by method of photometric determination on Nanocolor 500 D photometer (Macherey-Nagel, Germany) at the laboratory of the University of Nova Gorica. TOC measurements were done by differential method on the Analytic Jena Multi C/N 3100 analyzer. Toxicity was measured on analytic instrument LUMIStox-300 for analysing toxicity with the luminescent bacteria test. Measurements of cations and anions concentrations were performed at the National Institute of Chemistry in Ljubljana by the method of ion chromatography.

Results of measured variables varied considerably at the inflows, wetlands, and reservoir upper and main basin locations. EC, COD, $BOD_5$, and TOC levels were in general higher at the melioration ditches and at the wetlands, suggesting a possible organic matter overload. The nitrate-nitrogen ($NO_3$-N) concentrations were the highest at the stream inflows, which suggests a possible anthropogenic impact on reservoir stream inflows. The toxicity measurements showed presence of possible toxic elements for living organisms at the wetlands and at the upper basin on few occasions. The results of present study, when compared to the previous monitoring carried out at the upper basin and its inflows twenty years ago, show signs of aggravation of its state. Based on our observations, we believe that the ecological state of the reservoir upper basin will likely worsen, if an effective management with a mitigation approach is not established. Wetlands showed an undefined position suggesting that their buffering capacity and their role within the reservoir ecosystem should be investigated further.

Understanding the reservoir ecosystem, its drainage basin characteristics, characteristics of its inflows, and processes dynamics within the reservoir is essential to provide an effective management of the facility, which will in the long term ensure a healthy aquatic ecosystem for humans and all living communities.

# 9 POVZETEK

Večji del limnološke znanosti in razumevanja limnoloških procesov temelji na preučevanju ekosistemov naravnih jezer. Tako naravna kot umetna jezera so lentični sistemi in imajo veliko skupnih lastnosti, a vendar se umetna jezera v nekaterih značilnostih pomembno razlikujejo od naravnih jezerskih ekosistemov. Temeljna razlika med naravnimi in umetnimi jezerskimi ekosistemi je v antropogenem izvoru slednjih in le-ta pogojuje njihove limnološke značilnosti in njihov odziv na zunanje in notranje vplive, strese in obremenitve.

Človek ustvarja umetna jezera z zajezitvami in pregradami na potokih in rekah že več tisoč let. V zadnjih dveh stoletjih pa je gradnja vodnih zadrževalnikov postala izjemnega pomena predvsem pri zagotavljanju poplavne varnosti, proizvodnji električne energije in oskrbi urbanega in podeželskega prebivalstva s pitno vodo ter vodo za namakanje obdelovalnih površin. Akumulacije se načrtujejo in gradijo v obsegu brez primere kot odgovor na vse večje zahteve človeške populacije. Večina teh objektov je zgrajenih brez ozira na dejstvo, da poseganje in spreminjanje vodozbirnega sistema v območju pojezerja lahko pomembno vpliva na kakovost vode vodnih ekosistemov v spremenjenem območju. Površinske tekoče vode, potoki in reke, se na neki točki svoje poti izlivajo v zbirno vodno telo, bodisi naravno jezero, umetni zadrževalnik ali morje. Zato so jezera in akumulacije nekakšen odraz vseh naravnih in antropogenih procesov, ki se odvijajo v porečju vse do točke vtoka. V kolikor je ta 'koncept vpliva pojezerja' pri načrtovanju zadrževalnikov in umetnih jezerih spregledan in se ga ne upošteva, lahko posledice učinkov gradnje takega umetnega jezera dolgoročno pomembno vplivajo na vodne združbe in človekovo okolje v območju pojezerja in širše.

Čeprav so naravna in umetna jezera konstantno izpostavljena številnim naravnim in antropogenim stresnim dejavnikom, so antropogeni učinki tisti, ki v zadnjih desetletjih povzročajo veliko večje skrbi. Povečan učinek antropogenih aktivnosti na vodno okolje v zadnjih stoletjih ima za posledico degradiranost številnih vodnih ekosistemov. Kakovost voda ne ogrožajo le poselitev in kmetijska dejavnost, ampak tudi raba celinskih voda in njihovih vodozbirnih območij za različne namene.

Namen pričujoče naloge je bil ugotoviti morebiten vpliv antropogenih dejavnosti na kakovost vode v zadrževalniku Vogrščček. Zadrževalnik Vogrščček leži v zahodni Sloveniji v podeželskem območju spodnje Vipavske doline. Vipavska dolina je dobila ime po njenem osrednjem vodotoku, reki Vipavi. Zadrževalnik je nastal konec osemdesetih let z gradnjo pregrade na potoku Vogrščček, desnem pritoku reke Vipave. Osnovni namen zadrževalnika je zagotavljanje vode za namakanje kmetijskih površin in zadrževanje poplavnega vala. Pred polnjenjem je bil v območju zadrževalnika zgrajen nasip hitre ceste (HC Nova Gorica – Vipava), ki deli vodno telo zadrževalnika na dva dela, na ‘zgornje jezero’ (v nadaljevanju: zgornje jezero) in ‘glavno jezero’ (v nadaljevanju: glavno jezero). Zgornje jezero je zbiralnik glavnih večjih pritokov, ki gravitirajo na zadrževalnik, medtem ko glavno jezero predstavlja dejansko akumulacijo za namakalno vodo. Obe jezeri sta v preteklosti večkrat kazali znake evtrofikacije. Spričo dejstva, da se v zgornje jezero steka večina pritokov iz okoliških naselij, kmetijskih površin in prometnic, smo se pri naši nalogi osredotočili prav na zgornje jezero in njegove pritoke. Želeli smo ugotoviti morebiten vpliv antropogenih aktivnosti v pojezerju, kot so izpusti odpadnih vod iz gospodinjstev in različne kmetijske prakse, na kakovost vode zgornjega jezera in njegovih pritokov. Kot potencialne sprejemnike spiranja obremenjenih vod s kmetijskih površin smo v raziskavo vključili tudi nekatere melioracijske jarke, ki gravitirajo na zgornje jezero in njegove pritoke. V sklopu naše raziskave smo poskušali ugotoviti tudi morebitno varovalno sposobnost dveh naravnih mokrišč, ki sta se razvili na severo-vzhodnem robu zgornjega jezera, za blažitev vpliva obremenjenih pritokov iz pojezerja na zgornje jezero. Rezultate naše raziskave smo primerjali z rezultati in ugotovitvami predhodne raziskave izvedene na obravnavanem območju pred dvajsetimi leti in poskušali določiti nagib merjenih parametrov kakovosti vode v tem časovnem obdobju.

Spremljanje kakovosti vode je vključevalo sledeče parametre: temperaturo zraka in vode (T), pH, električno prevodnost (EC), koncentracijo raztopljenega kisika (DO), nasičenost vode s kisikom, kemijsko potrebo po kisiku (KPK), biološko oziroma biokemijsko potrebo po kisiku ($BPK_5$), koncentracijo organsko vezanega ogljika (TOC), koncentracije kalcija ($Ca^{2+}$), magnezija ($Mg^{2+}$), kalija ($K^+$), amonijevega iona ($NH_4^+$), natrija ($Na^+$), fluorida ($F^-$), klorida ($Cl^-$), bromida ($Br^-$), nitrita ($NO_2^-$), nitrata ($NO_3^-$), sulfata ($SO_4^{2-}$), orto-fosfata ($PO_4^{3-}$) in toksičnost vode. Terensko delo, vzorčevanje in laboratorijske analize so bile opravljene v skladu s standardnimi metodami prevzetimi za spremljanje in določanje kakovosti vode. Lokacije odvzemov smo določili na podlagi preučitve značilnosti drenažnega vzorca zadrževalnika in natančnega terenskega ogleda. Meritve temperature vode, pH, EC, DO in nasičenosti s kisikom so bile izvedene *in situ* z uporabo WTW (Wissenschaftlich-Technische-Werkstätlen, Weilheim, Germany) MultiLine P4 univerzalnega prenosnega merilca. Koncentracije KPK, $BPK_5$ in $NH_4^+$ smo določili s fotometrično metodo z uporabo Nanocolor 500 D fotometra (Macherey-Nagel, Germany) v laboratoriju Univerze v Novi Gorici. TOC smo določali z diferencialno metodo, z uporabo Analytic Jena Multi C/N 3100 analizatorja. Toksičnost vzorcev vode smo merili z uporabo analitičnega instrumenta LUMIStox-300 za analizo toksičnosti vzorcev z luminiscentnimi bakterijskimi testi. Koncentracije kationov in anionov smo določali z metodo ionske kromatografije na Kemijskem Inštitutu v Ljubljani.

Rezultati merjenih parametrov so pokazali precejšnje razlike med lokacijami na pritokih, mokriščih ter na zgornjem in glavnem jezeru. EC, COD, $BOD_5$, in TOC koncentracije so bile večinoma višje na lokacijah melioracijskih jarkov in na območjih mokrišč, kar izkazuje možnost obremenjenosti teh lokacij z organsko snovjo. Koncentracije nitrata oziroma dušika vezanega v nitrat ($NO_3$-N) so bile višje na lokacijah pritokov, ki se stekajo v zgornje jezero. Slednje nakazuje možnost, da so pritoki zgornjega jezera lahko izpostavljeni antropogenim učinkom. Meritve toksičnosti so na lokacijah mokrišč in zgornjega jezera ob posameznih priložnostih izkazale vsebnost mogočih toksičnih snovi za žive organizme v vodi. Pri primerjavi rezultatov obravnavanih v pričujoči nalogi z rezultati iz naloge o kakovosti vode na zgornjem jezeru in njegovih pritokih izvedene pred dvajsetimi leti, smo ugotovili trend poslabšanja stanja. Na podlagi naših ugotovitev menimo, da se bo ekološko stanje zgornjega jezera najverjetneje še naprej slabšalo, v kolikor ne bo zagotovljenega učinkovitega upravljanja z območjem zadrževalnika, ki bo vključevalo ustrezne ukrepe za omilitev obremenitev iz pojezerja. Vloge mokrišč in njihove sposobnosti za blažitev vplivov in obremenitev iz pojezerja ni bilo mogoče povsem opredeliti. Menimo, da bi bile potrebne nadaljnje podrobnejše raziskave za natančnejšo opredelitev vloge mokrišč v ekosistemu zadrževalnika.

Poznavanje ekosistema zadrževalnika, značilnosti pojezerja, pritokov in dinamike procesov znotraj zadrževalnika samega je nujno za dosego kakovostnega in celovitega upravljanja z zadrževalnikom, ki dolgoročno zagotavlja zdrav vodni ekosistem za vse nanj vezane življenjske združbe in za človeka.

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# ACKNOWLEDGMENT

I owe my biggest and sincerest thanks to my dear parents Marija and Andrej Zega who helped and supported me unconditionally.

I would sincerely like to acknowledge my mentor prof. dr. Barbara Čenčur Curk for her exceptional professional assistance and counselling.

I would also like to acknowledge Mr. Zlatko Gabrijelčič for generously sharing with me all his knowledge about the Vogrščljek reservoir facility and for his indispensable help in selecting the sampling locations.

Many thanks to the representatives of Hidrotehnik d.d. and MOP, ARSO, Oddelek za povodje reke Soče, for providing to me all the water quality monitoring reports, studies, and documentation about Vogrščljek reservoir.

I express my sincerest gratitude to:

- my family and friends: Andreja Zega, Ema Kerkoč, Matija Kerkoč, Andraž Kerkoč, Urša Škumavc, Tjaša Leskovič Vendramin, Gašper Kodele and Priscila Gulič, who voluntarily helped me with the field work. I'd have never made it so smooth without you!
- my colleague Klavdij Bajc for his professional help in identifying the plant species.
- Jelka Jelnikar and dr. Andreja Drolc for their counselling regarding ion chromatography analyses.
- Dunja Mahne and Andreja Šuligoj for their great assistance in the laboratory for environmental research at University of Nova Gorica.
- marvellous librarians: Vanesa, Marjetka and Mirjana in the library of University of Nova Gorica for their amazing response in providing articles, publications and studies I needed.
- Professional designer Majda Kunst for her help in elaboration of figures.
- 'the magician' Tomaž Mihelj for helping me out with all the computer issues.
- Tina Pergar for editing the thesis.

Thank you all very much!

*Apendix 1: Fieldwork sample list*

## TERENSKI VZORČNI LIST

Mesto odvzema: ______________________________ Vreme: _________________________

Ime vzorca: ____________________

Datum: __________

Ura: ___________

gladina vode (relativna): ____________

**MERITVE TEREN**

T zrak: _________ $^0$C pH (pri $^0$C) : __________

T voda: _________ $^0$C elektroprevodnost – E (pri $^0$C): ____________ µScm$^{-1}$

koncentracija O2 ___________________ mgl$^{-1}$

nasičenost O2 _____________________ mgl$^{-1}$

**MERITVE LABORATORIJ**

Barva (?): ________________________ (Op. vzorec do izvedbe hranjen pri T $^0$C)

BOD$_5$ (BPK$_5$): ___________________ mgl$^{-1}$ (Op. vzorec do izvedbe hranjen pri T $^0$C)

COD$_5$ (KPK$_5$): ___________________ mgl$^{-1}$ (Op. vzorec do izvedbe hranjen pri T $^0$C)

TOC: ___________________ mgl$^{-1}$ (C) (Op. vzorec do izvedbe hranjen pri T $^0$C)

Amonij: __________________ mgl$^{-1}$ (NH$_4$) (Op. vzorec do izvedbe hranjen pri T $^0$C)

Nitriti: ___________________ mgl$^{-1}$ (NO$_2$) (Op. vzorec do izvedbe hranjen pri T $^0$C)

Nitrati: ___________________ mgl$^{-1}$ (NO$_3$) (Op. vzorec do izvedbe hranjen pri T $^0$C)

Sulfati: ___________________ mgl$^{-1}$ (SO$_4$) (Op. vzorec do izvedbe hranjen pri T $^0$C)

Kloridi: ___________________ mgl$^{-1}$ (Cl) (Op. vzorec do izvedbe hranjen pri T $^0$C)

Fosfati: ___________________mgl$^{-1}$ (PO$_4$) (Op. vzorec do izvedbe hranjen pri T $^0$C)

Toksičnost (vibrio fischeri): _______________________

OPOMBE:

______________________________________________________________________________

_________________________________________________________________________

### *Appendix 2.1: Table of data and results of measured variables at VOG2 location*

**sample VOG2 (stream Vogršček; running water)** **Physical - Chemical analyses**

| **Variable** | **Unit** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14.3.2010 | 3.4.2010 | 6.6.2010 | 17.6.2010 | 21.7.2010 | 11.8.2010 | 5.9.2010 | 28.9.2010 | 23.10.2010 | 20.11.2010 | |
| notes | | | | | | low flow | bad odour | | high flow | | high flow | |
| time/weather | hour | 9:00/sunny | 9:21/sunny | 8:05/sunny | / | 10:10/sunny | 10:22/clear | 10:35/cloudy | 10:52/cloudy | 10:33/cloudy | 10:25/cloudy | |
| T air | oC | 7 | 12 | 15,7 | / | 25,6 | 19,4 | 19,5 | 16 | 15 | 12,7 | |
| T water | oC | 8 | 9,2 | 12,7 | / | 16,7 | 16,3 | 14,6 | 14,1 | 11,4 | 12,3 | |
| pH | | 8,5 | 8,6 | 8,27 | / | 8,05 | 7,9 | 8,16 | 7,95 | 8,18 | 8,22 | 8,2 |
| Electrical conductivity (EC) | µScm-1 | 346 | 438 | 356 | / | 364 | 422 | 430 | 426 | 382 | 440 | 400 |
| Oxygen concentration | mgl-1 | / | / | / | / | / | 8,1 | 7,68 | 7,67 | 9,4 | 9 | 8,4 |
| Oxygen saturation | % | / | / | / | / | / | 84 | 76 | 75,4 | 86,1 | 87,7 | 81,8 |
| Colour | | none | none | none | / | none | none | none | none | none | none | |
| COD | mgl-1 | <5 | 4,3 | 6 | / | 5,6 | 5 | 5 | 5 | 4 | 5,2 | 5 |
| BOD5 | mgl-1 | / | / | / | / | / | / | / | / | / | / | |
| Total Carbon (TC) | mgl-1 | inconclusive | / | / | / | 47,62 | 44,77 | 48,43 | inconclusive | 44,98 | inconclusive | |
| Total Organic Carbon (TOC) | mgl-1 | inconclusive | / | / | / | 4,44 | 1,69 | 1,82 | inconclusive | 3,22 | inconclusive | 2,8 |
| Ammonium - ion NH4+ | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrite NO2- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrate NO3- | mgl-1 | / | 4,11 | 3,15 | / | 2,75 | 6,3 | 5,8 | 4,09 | 4,25 | 4,51 | |
| Nitrate nitrogen (NO3-N) | mgl-1 | / | 0,93 | 0,71 | / | 0,62 | 1,42 | 1,31 | 0,92 | 0,96 | 1,02 | 0,99 |
| Phosphate PO43- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Sulphate SO42- | mgl-1 | / | 14,5 | 8,79 | / | 4,61 | 9,5 | 9,18 | 8,5 | 6,95 | 11,4 | 9,2 |
| Chloride Cl- | mgl-1 | / | 5,33 | 2,39 | / | 2,21 | 4,43 | 4,15 | 2,29 | 2,6 | 2,42 | 3,2 |
| Fluoride F- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Bromide Br- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| | | | | | | | | | | | | |
| Sodium Na+ | mgl-1 | / | / | / | / | 2,1 | 4,62 | 5,04 | 2,64 | 3,14 | 2,97 | 3,4 |
| Potassium K+ | mgl-1 | / | / | / | / | <1 | 2,99 | 3,95 | <1 | <1 | <1 | |
| Magnesium Mg 2+ | mgl-1 | / | / | / | / | 1,4 | 2,71 | 2,76 | 2,96 | 2,36 | 3,17 | 2,6 |
| Calcium Ca 2+ | mgl-1 | / | / | / | / | 31,7 | 55,1 | 55,8 | 29,3 | 33,1 | 51,5 | 42,75 |
| | | | | | | | | | | | | |
| Toxicity analyses *(Vibrio fisheri)* | % | / | / | / | / | / | -4,32 | / | 10,06 | / | / | |

## *Appendix 2.2: Table of data and results of measured variables at VOG3 location*

**sample VOG3 (stream Vogršček; running water)**

**Physical - Chemical analyses**

| **Variable** | **Unit** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14.3.2010 | 3.4.2010 | 6.6.2010 | 17.6.2010 | 21.7.2010 | 11.8.2010 | 5.9.2010 | 28.9.2010 | 23.10.2010 | 20.11.2010 | |
| notes | | | | | | | | | | | high flow | |
| time/weather | | 9:15/sunny | 9:37/sunny | 8:41/sunny | / | 10:53/sunny | 11:15/clear | 11:05/cloudy | 11:18/cloudy | 11:00/cloudy | 10:50/cloudy | |
| T air | oC | 8,5 | 11 | 17,3 | / | 25,6 | 21,2 | 19 | 16 | 14 | 12,8 | |
| T water | oC | 7,8 | 9,1 | 12,8 | / | 17,3 | 16,7 | 14,7 | 14,2 | 11,4 | 12,4 | 12,9 |
| pH | | 8,38 | 8,4 | 8,12 | / | 8,03 | 8 | 8 | 7,94 | 8,19 | 8,09 | 8,1 |
| Electrical conductivity (EC) | µScm-1 | 347 | 433 | 357 | / | 367 | 425 | 431 | 424 | 384 | 439 | 401 |
| Oxygen concentration | mgl-1 | / | / | / | / | / | 8 | 7,42 | 7,46 | 9 | 9,33 | 8,4 |
| Oxygen saturation | % | / | / | / | / | / | 84 | 73,9 | 73,5 | 83,6 | 87,4 | 80,5 |
| Colour | | none | none | none | / | none | none | none | none | none | none | |
| COD | mgl-1 | <5 | 5 | 3 | / | 4 | 5 | 11 | 5 | 4 | 8 | 5,6 |
| BOD5 | mgl-1 | / | / | / | / | / | / | 2,1 | / | / | / | |
| Total Carbon (TC) | mgl-1 | inconclusive | / | / | / | 47,32 | 43,57 | 50,09 | inconclusive | 45,36 | inconclusive | |
| Total Organic Carbon (TOC) | mgl-1 | inconclusive | / | / | / | 3,63 | 1,39 | 2,91 | inconclusive | 2,58 | inconclusive | 2,6 |
| Ammonium - ion NH4+ | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrite NO2- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrate NO3- | mgl-1 | / | 4,22 | 3,04 | / | 4,71 | 6 | 5,5 | 4,1 | 4,19 | 4,41 | |
| Nitrate nitrogen (NO3-N) | mgl-1 | / | 0,95 | 0,69 | / | 1,06 | 1,35 | 1,24 | 0,93 | 0,95 | 0,99 | 1,02 |
| Phosphate PO43- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Sulphate SO42- | mgl-1 | / | 14,5 | 8,81 | / | 6,57 | 9,1 | 8,92 | 9,06 | 7,18 | 11,2 | 9,4 |
| Chloride Cl- | mgl-1 | / | 6,92 | 2,37 | / | 3,56 | 4,39 | 4,18 | 2,29 | 2,61 | 2,42 | 3,6 |
| Fluoride F- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Bromide Br- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| | | | | | | | | | | | | |
| Sodium Na+ | mgl-1 | / | / | / | / | 3,23 | 4,6 | 5 | 2,88 | 2,97 | 3 | 3,6 |
| Potassium K+ | mgl-1 | / | / | / | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Magnesium Mg 2+ | mgl-1 | / | / | / | / | 2,02 | 2,78 | 2,82 | 3,14 | 2,45 | 3,36 | 2,8 |
| Calcium Ca 2+ | mgl-1 | / | / | / | / | 46,7 | 53,2 | 54,6 | 36,2 | 36,6 | 46,1 | 45,6 |
| | | | | | | | | | | | | |
| Toxicity analyses *(Vibrio fisheri)* | % | / | / | / | / | / | -2,18 | / | 6,86 | / | / | |

### *Appendix 2.3: Table of data and results of measured variables at VOG4 location*

**sample VOG4 (stream Vogršček before inflow; stagnant water)** **Physical - Chemical analyses**

| **Variable** | **Unit** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14.3.2010 | 3.4.2010 | 6.6.2010 | 17.6.2010 | 21.7.2010 | 11.8.2010 | 5.9.2010 | 28.9.2010 | 23.10.2010 | 20.11.2010 | |
| notes | | | | | | | turbid water | | turbid water | | | |
| time/weather | | 11:40/sunny | 12:00/sunny | 11:42/sunny | 16:41/variably | 14:20/sunny | 14:23/clear | 14:03/cloudy | 14:30/cloudy | 14:00/cloudy | 13:15/cloudy | |
| T air | oC | 12,8 | 17,4 | 24,9 | 21 | 28,5 | 26,7 | 22,5 | 16 | 16 | 14,9 | |
| T water | oC | 9 | 10,7 | 14,3 | 24,9 | 29,5 | 28,8 | 21,8 | 14,6 | 12,3 | 12,8 | |
| pH | | 8,38 | 8,34 | 8,14 | 8,05 | 8,22 | 8,27 | 8,05 | 7,94 | 7,9 | 8,21 | 8,1 |
| Electrical conductivity (EC) | µScm-1 | 346 | 432 | 362 | 309 | 298 | 262 | 327 | 423 | 386 | 442 | 359 |
| Oxygen concentration | mgl-1 | / | / | / | / | / | 7,5 | 6,45 | 7,15 | 7,8 | 8,12 | 7,4 |
| Oxygen saturation | % | / | / | / | / | / | 98,3 | 73,9 | 71,3 | 73,2 | 77,5 | 78,8 |
| Colour | | none | none | none | none | none | none | none | none | ery pale jellow | none | |
| COD | mgl-1 | <5 | 3,3 | 5,3 | 10,5 | 11 | 11 | 11 | 6 | 6 | 6 | 7,8 |
| BOD5 | mgl-1 | / | / | / | <2 | 3 | 5,4 | <2 | / | / | 2,1 | |
| Total Carbon (TC) | mgl-1 | inconclusive | / | / | / | 38,67 | 29,8 | 39,25 | 50,44 | 45,46 | inconclusive | |
| Total Organic Carbon (TOC) | mgl-1 | inconclusive | / | / | / | 5,38 | 4,45 | 3,26 | 4,67 | 2,49 | inconclusive | 4,05 |
| Ammonium - ion NH4+ | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrite NO2- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrate NO3- | mgl-1 | / | 3,99 | 3,01 | 1,41 | 1,08 | <1 | <1 | 4,04 | 3,95 | 4,4 | |
| Nitrate nitrogen (NO3-N) | mgl-1 | / | 0,9 | 0,68 | 0,32 | 0,24 | / | / | 0,91 | 0,89 | 0,99 | 0,7 |
| Phosphate PO43- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Sulphate SO42- | mgl-1 | / | 15,5 | 8,98 | 6,86 | 4,33 | 8 | 7,59 | 9,22 | 7,26 | 10,8 | 8,7 |
| Chloride Cl- | mgl-1 | / | 6,31 | 2,52 | 2,55 | 1,79 | 3,27 | 3,06 | 2,5 | 2,64 | 2,58 | 3 |
| Fluoride F- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Bromide Br- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| | | | | | | | | | | | | |
| Sodium Na+ | mgl-1 | / | / | / | / | 1,64 | 3,43 | 3,78 | 2,84 | 3,05 | 3,08 | 3 |
| Potassium K+ | mgl-1 | / | / | / | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Magnesium Mg 2+ | mgl-1 | / | / | / | / | 1,54 | 2,81 | 3,07 | 2,95 | 2,43 | 3,2 | 2,6 |
| Calcium Ca 2+ | mgl-1 | / | / | / | / | 17,7 | 27,8 | 41,8 | 40,4 | 38,2 | 43,2 | 34,85 |
| | | | | | | | | | | | | |
| Toxicity analyses *(Vibrio fisheri)* | % | / | / | / | -6,22 | / | -1,98 | / | 19,9 | / | 3,56 | |

### *Appendix 2.4: Table of data and results of measured variables at VOG-J1 location*

**sample VOG-J1 (upper basin)** **Physical - Chemical analyses**

| **Variable** | **Unit** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14.3.2010 | 3.4.2010 | 6.6.2010 | 17.6.2010 | 21.7.2010 | 11.8.2010 | 5.9.2010 | 28.9.2010 | 23.10.2010 | 20.11.2010 | |
| notes | | | | | | | | | | | turbid water | |
| time/weather | | 10:11/sunny | 10:42/sunny | 10:05/sunny | 16:22/variably | 12:35/sunny | 12:18/clear | 12:20/cloudy | 12:30/cloudy | 12:10/cloudy | 11:40/cloudy | |
| T air | oC | 12,2 | 14,5 | 24,5 | 23,6 | 29 | 28,6 | 22 | 17,1 | 16 | 14 | |
| T water | oC | 6,6 | 12,5 | 20,3 | 25,1 | 28,1 | 28,2 | 21,5 | 16,2 | 12,9 | 12,5 | |
| pH | | 8,22 | 8,14 | 7,9 | 8,13 | 8,13 | 7,98 | 8 | 7,93 | 7,95 | 7,9 | 8 |
| Electrical conductivity (EC) | µScm-1 | 353 | 360 | 342 | 306 | 293 | 266 | 324 | 357 | 394 | 420 | 341 |
| Oxygen concentration | mgl-1 | / | / | / | / | / | 6,6 | 7,3 | 7,21 | 6,13 | 7,72 | 7 |
| Oxygen saturation | % | / | / | / | / | / | 85 | 83,5 | 74,1 | 58,4 | 73,1 | 74,8 |
| Colour | | none | none | none | none | none | none | none | pale jellow | ery pale jellow | none | |
| COD | mgl-1 | <5 | 5,6 | 8,5 | 13 | 10 | 11 | 13 | 10 | 10,6 | 8 | 10 |
| BOD5 | mgl-1 | / | 3,2 | <2 | <2 | / | / | 2,7 | / | <2 | / | |
| Total Carbon (TC) | mgl-1 | inconclusive | / | / | / | 38,22 | 30,28 | 40,21 | 44,67 | 49,11 | inconclusive | |
| Total Organic Carbon (TOC) | mgl-1 | inconclusive | / | / | / | 5,46 | 5,05 | 5,5 | 5,98 | 4,73 | inconclusive | 5,3 |
| Ammonium - ion NH4+ | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrite NO2- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | / | |
| Nitrate NO3- | mgl-1 | / | 2,78 | 2,71 | 1,41 | <1 | <1 | <1 | 2,73 | 2,12 | / | |
| Nitrate nitrogen (NO3-N) | mgl-1 | / | 0,63 | 0,61 | 0,32 | / | / | / | 0,62 | 0,48 | / | 0,53 |
| Phosphate PO43- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | / | |
| Sulphate SO42- | mgl-1 | / | 9,6 | 8,71 | 6,72 | 5,39 | 8,6 | 7,63 | 7,03 | 6,46 | / | 7,5 |
| Chloride Cl- | mgl-1 | / | 5,53 | 2,44 | 2,53 | 2,04 | 3,29 | 3,05 | 1,99 | 2,38 | / | 2,9 |
| Fluoride F- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | / | |
| Bromide Br- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | / | |
| | | | | | | | | | | | / | |
| Sodium Na+ | mgl-1 | / | / | / | / | 2,08 | 3,58 | 3,78 | 2,41 | 2,83 | / | 2,9 |
| Potassium K+ | mgl-1 | / | / | / | / | <1 | <1 | <1 | <1 | <1 | / | |
| Magnesium Mg 2+ | mgl-1 | / | / | / | / | 1,92 | 2,94 | 3,1 | 2,75 | 2,72 | / | 2,7 |
| Calcium Ca 2+ | mgl-1 | / | / | / | / | 28 | 36,2 | 42,5 | 37 | 40,9 | / | 36,9 |
| | | | | | | | | | | | | |
| Toxicity analyses *(Vibrio fisheri)* | % | / | / | / | 3,42 | / | -3,58 | / | 17,72 | / | / | |

### *Appendix 2.5: Table of data and results of measured variables at VOG-J2 location*

**sample VOG-J2 (wetland-1 edge)** **Physical - Chemical analyses**

| **Variable** | **Unit** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14.3.2010 | 3.4.2010 | 6.6.2010 | 17.6.2010 | 21.7.2010 | 11.8.2010 | 5.9.2010 | 28.9.2010 | 23.10.2010 | 20.11.2010 | |
| notes | | | | | | | | | decay odour | | | |
| time/weather | | 9:34/sunny | 9:57/sunny | 9:16/sunny | 15:30/variably | 11:02/sunny | 11:35/clear | 11:25/cloudy | 11:40/cloudy | 11:32/cloudy | 11:10/cloudy | |
| T air | oC | 10 | 14,5 | 20,5 | 23,6 | 28 | 23,3 | 20,2 | 17,1 | 15 | 13,7 | |
| T water | oC | 6,7 | 11,7 | 19,6 | 25,9 | 28,3 | 26,5 | 21,2 | 16 | 12,4 | 12,3 | |
| pH | | 8,33 | 8,16 | 7,69 | 7,9 | 7,99 | 7,65 | 7,78 | 8 | 7,91 | 7,71 | 7,9 |
| Electrical conductivity (EC) | µScm-1 | 353 | 359 | 344 | 310 | 295 | 270 | 329 | 362 | 394 | 423 | 344 |
| Oxygen concentration | mgl-1 | / | / | / | / | / | 5,1 | 5,65 | 6,02 | 6,62 | 5,56 | 5,8 |
| Oxygen saturation | % | / | / | / | / | / | 64 | 64,1 | 61,8 | 62,4 | 53 | 61 |
| Colour | | none | none | none | none | none | none | none | none | none | none | |
| COD | mgl-1 | <5 | 5 | 9,3 | 9 | 15 | 12 | 11,6 | 9,5 | 6 | 8 | 9,5 |
| BOD5 | mgl-1 | / | / | <2 | 5,5 | 5,7 | 4,1 | / | / | / | 2,1 | |
| Total Carbon (TC) | mgl-1 | inconclusive | / | / | / | 39,13 | 32,48 | 37,42 | 48,15 | 46,7 | inconclusive | |
| Total Organic Carbon (TOC) | mgl-1 | inconclusive | / | / | / | 5,88 | 6,46 | 4,33 | 5,72 | 3,38 | inconclusive | 5,1 |
| Ammonium - ion NH4+ | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrite NO2- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrate NO3- | mgl-1 | / | 1,37 | 2,37 | 1,1 | <1 | <1 | <1 | 2,63 | 1,89 | 3,48 | |
| Nitrate nitrogen (NO3-N) | mgl-1 | / | 0,31 | 0,53 | 0,25 | / | / | / | 0,59 | 0,43 | 0,79 | 0,48 |
| Phosphate PO43- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Sulphate SO42- | mgl-1 | / | 3,1 | 8,37 | 7 | 7,35 | 8,3 | 6,51 | 6,63 | 6,49 | 9,8 | 7 |
| Chloride Cl- | mgl-1 | / | 2,11 | 2,29 | 2,61 | 3,29 | 3,2 | 2,63 | 2,04 | 2,5 | 2,47 | 2,6 |
| Fluoride F- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Bromide Br- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| | | | | | | | | | | | | |
| Sodium Na+ | mgl-1 | / | / | / | / | 3,34 | 3,46 | 3,26 | 2,5 | 3 | 3,01 | 3,1 |
| Potassium K+ | mgl-1 | / | / | / | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Magnesium Mg 2+ | mgl-1 | / | / | / | / | 2,78 | 2,82 | 2,76 | 2,95 | 2,81 | 3,4 | 2,9 |
| Calcium Ca 2+ | mgl-1 | / | / | / | / | 32 | 35,3 | 35,3 | 31,6 | 42,2 | 46,2 | 37,1 |
| | | | | | | | | | | | | |
| Toxicity analyses *(Vibrio fisheri)* | % | / | / | / | -3,62 | / | -2,46 | / | 9,94 | / | 6,32 | |
| relative water level | cm | 0 | 0 | 0,5 | 0 | -3 | -2,5 | -2 | 2 | 0 | 1 | |

***Appendix 2.6: Table of data and results of measured variables at VOG-J3 location***

**sample VOG-J3 (wetland-1)**

**Physical - Chemical analyses**

| **Variable** | **Unit** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14.3.2010 | 3.4.2010 | 6.6.2010 | 17.6.2010 | 21.7.2010 | 11.8.2010 | 5.9.2010 | 28.9.2010 | 23.10.2010 | 20.11.2010 | |
| notes | | | | | | | low water | decay odour | | low water | | |
| time/weather | | 9:46/sunny | 10:22/sunny | 9:40/sunny | 16:03/variably | 12:23/sunny | 11:50/clear | 11:45/cloudy | 12:05/cloudy | 11:45/cloudy | 11:20/cloudy | |
| T air | oC | 10 | 14,5 | 20,5 | 23,6 | 27 | 25,4 | 19,6 | 17 | 15 | 14,2 | |
| T water | oC | 5 | 10,1 | 18,6 | 24,3 | 25,1 | 21,2 | 17 | 15,2 | 10,6 | 11,2 | |
| pH | | 7,85 | 7,43 | 7,28 | 6,88 | 7,42 | 7,14 | *7,4 | *7,36 | *7,51 | 7,13 | 7,3 |
| Electrical conductivity (EC) | µScm-1 | 351 | 363 | 351 | 338 | 313 | 274 | *332 | *527 | *438 | 420 | 371 |
| Oxygen concentration | mgl-1 | / | / | / | / | / | 1,5 | *2,95 | *1,7 | *5,7 | 4,85 | 3,3 |
| Oxygen saturation | % | / | / | / | / | / | 16 | *30,1 | *17,1 | *51,8 | 44,2 | 31,8 |
| Colour | | none | none | none | pale yellow | pale yellow | none | none | pale yellow | ery pale jellow | pale yellow | |
| COD | mgl-1 | 6 | 8 | 13 | 20 | 17,3 | 12,3 | 11 | 16,2 | 15 | 13,5 | 13,2 |
| BOD5 | mgl-1 | / | <2 | <2 | 4,5 | 6,1 | 4,5 | <2 | / | <2 | 2,8 | |
| Total Carbon (TC) | mgl-1 | inconclusive | / | / | / | 41,74 | 35,32 | 39,27 | 75,84 | 58,08 | inconclusive | |
| Total Organic Carbon (TOC) | mgl-1 | inconclusive | / | / | / | 5,4 | 7,26 | 4,21 | 15,73 | 9,62 | inconclusive | 8,4 |
| Ammonium - ion NH4+ | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrite NO2- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrate NO3- | mgl-1 | / | 2,26 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrate nitrogen (NO3-N) | mgl-1 | / | 0,51 | / | / | / | / | / | / | / | / | |
| Phosphate PO43- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Sulphate SO42- | mgl-1 | / | 10,7 | 7,16 | 1,93 | 4,47 | 7,8 | 6,79 | 4,57 | 4,42 | 4,34 | 5,8 |
| Chloride Cl- | mgl-1 | / | 6,47 | 1,67 | <1 | 1,47 | 2,93 | 3,23 | 2,29 | 2,25 | 2,62 | 2,5 |
| Fluoride F- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Bromide Br- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| | | | | | | | | | | | | |
| Sodium Na+ | mgl-1 | / | / | / | / | 1,46 | 3,64 | 3,71 | 5,26 | 3,13 | 3,85 | 3,5 |
| Potassium K+ | mgl-1 | / | / | / | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Magnesium Mg 2+ | mgl-1 | / | / | / | / | 1,47 | 2,9 | 3,11 | 5,89 | 3,24 | 4,74 | 3,5 |
| Calcium Ca 2+ | mgl-1 | / | / | / | / | 24,3 | 39,7 | 37,9 | 33,5 | 39,4 | 57,6 | 38,7 |
| | | | | | | | | | | | | |
| Toxicity analyses *(Vibrio fisheri)* | % | / | / | / | 26,54 | / | -1,66 | 23,6 | 13,48 | / | / | |

*low water level; WTW held in diagonal

## *Appendix 2.7: Table of data and results of measured variables at VOG-J4 location*

**sample VOG-J4 (wetland-2)** **Physical - Chemical analyses**

| **Variable** | **Unit** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14.3.2010 | 3.4.2010 | 6.6.2010 | 17.6.2010 | 21.7.2010 | 11.8.2010 | 5.9.2010 | 28.9.2010 | 23.10.2010 | 20.11.2010 | |
| notes | | | | | | | | | | | decay odour | |
| time/weather | | 12:10/sunny | 12:25/sunny | 12:33/sunny | 17:29/variably | 15:00/sunny | 15:10/clear | 14:45/cloudy | 15:05/cloudy | 14:40/cloudy | 13:45/cloudy | |
| T air | oC | 15,3 | 15 | 25,5 | 22,5 | 28,5 | 27,4 | 23 | 17 | 16 | 15,2 | |
| T water | oC | 7,1 | 13,1 | 22,6 | 24,4 | 29,2 | 28,4 | 21 | 16,5 | 13,3 | 11,8 | |
| pH | | 8,16 | 8,29 | 7,82 | 7,48 | 8,03 | 8 | *7,74 | *7,45 | *7,88 | 7,13 | 7,8 |
| Electrical conductivity (EC) | µScm-1 | 345 | 351 | 327 | 303 | 296 | 261 | *326 | *358 | *369 | 257 | 319 |
| Oxygen concentration | mgl-1 | / | / | / | / | / | 6,24 | *4,8 | *5,11 | *6,53 | 2,21 | 5 |
| Oxygen saturation | % | / | / | / | / | / | 81,2 | *54,5 | *53,1 | *62,8 | 21,2 | 54,6 |
| Colour | | none | none | none | pale yellow | none | none | none | ery pale yellow | ery pale jellow | pale yellow | |
| COD | mgl-1 | <5 | 6 | 11 | 10,6 | 10,6 | 13 | 10,3 | 11 | 7 | 20 | 11 |
| BOD5 | mgl-1 | / | / | <2 | 4,4 | 4,8 | 4,4 | 2,2 | / | 2'4 | <2 | |
| Total Carbon (TC) | mgl-1 | inconclusive | / | / | / | 37,75 | 31,72 | 38,44 | 44,72 | 46,67 | inconclusive | |
| Total Organic Carbon (TOC) | mgl-1 | inconclusive | / | / | / | 4,95 | 5,47 | 3,99 | 5,59 | 3,71 | inconclusive | 4,7 |
| Ammonium - ion NH4+ | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrite NO2- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrate NO3- | mgl-1 | / | 2,82 | 2,99 | 1,2 | <1 | <1 | <1 | 1,41 | 2,05 | <1 | |
| Nitrate nitrogen (NO3-N) | mgl-1 | / | 0,64 | 0,67 | 0,27 | / | / | / | 0,32 | 0,46 | / | 0,47 |
| Phosphate PO43- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Sulphate SO42- | mgl-1 | / | 11,8 | 8,06 | 6,62 | 6,57 | 8,4 | 7,69 | 6,02 | 6,21 | 4,4 | 7,3 |
| Chloride Cl- | mgl-1 | / | 5,63 | 2,47 | 2,49 | 2,76 | 3,32 | 3,07 | 2,59 | 2,47 | 2,2 | 3 |
| Fluoride F- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Bromide Br- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| | | | | | | | | | | | | |
| Sodium Na+ | mgl-1 | / | / | / | / | 2,72 | 3,53 | 3,76 | 2,32 | 2,83 | 2,21 | 2,9 |
| Potassium K+ | mgl-1 | / | / | / | / | <1 | 1,46 | <1 | <1 | <1 | <1 | |
| Magnesium Mg 2+ | mgl-1 | / | / | / | / | 2,36 | 2,8 | 3,13 | 2,37 | 2,64 | 1,64 | 2,5 |
| Calcium Ca 2+ | mgl-1 | / | / | / | / | 30,2 | 31,7 | 42,2 | 37,2 | 31,4 | 33,2 | 34,3 |
| | | | | | | | | | | | | |
| Toxicity analyses *(Vibrio fisheri)* | % | / | / | / | 0,92 | / | -8,38 | / | 7,04 | / | 20,58 | |
| relative water level | cm | 0 | 0 | 0 | 0 | -3 | -2 | -2,3 | 2 | 0 | 1 | |

*low water level; WTW held in diagonal

## *Appendix 2.8: Table of data and results of measured variables at VOG-J5 location*

**sample VOG-J5 (upper basin)** **Physical - Chemical analyses**

| **Variable** | **Unit** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14.3.2010 | 3.4.2010 | 6.6.2010 | 17.6.2010 | 21.7.2010 | 11.8.2010 | 5.9.2010 | 28.9.2010 | 23.10.2010 | 20.11.2010 | |
| notes | | | | | | | | | | | | |
| time/weather | | 12:23/sunny | 12:42/sunny | 12:50/sunny | / | 15:32/sunny | 15:35/clear | 15:15/cloudy | 15:32/cloudy | 15:10/cloudy | 14:15/cloudy | |
| T air | oC | 14,4 | 15 | 25,5 | / | 28,5 | 28,2 | 22,2 | 17 | 15 | 14,7 | |
| T water | oC | 6,3 | 13 | 24,5 | / | 29,6 | 29,3 | 21,9 | 16,5 | 13,1 | 12,9 | |
| pH | | 8,42 | 8,75 | 8,16 | / | 8,25 | 8,33 | 8,13 | 8,14 | 7,85 | 7,78 | 8,2 |
| Electrical conductivity (EC) | µScm-1 | 349 | 350 | 328 | / | 295 | 257 | 327 | 354 | 394 | 409 | 340 |
| Oxygen concentration | mgl-1 | / | / | / | / | / | 8,3 | 6,75 | 7 | 5,55 | 6,2 | 6,8 |
| Oxygen saturation | % | / | / | / | / | / | 109 | 77,6 | 72,8 | 53,3 | 59,3 | 74,4 |
| Colour | | none | none | none | / | none | none | none | ery pale yellow | ery pale jellow | none | |
| COD | mgl-1 | <5 | 4,6 | 9 | / | 11 | 12 | 12 | 9,5 | 10 | 9 | 9,6 |
| BOD5 | mgl-1 | / | / | <2 | / | 2,7 | 4,2 | 2 | / | <2 | <2 | |
| Total Carbon (TC) | mgl-1 | inconclusive | / | / | / | 38,74 | 32,86 | 39,72 | 42,58 | 47,82 | inconclusive | |
| Total Organic Carbon (TOC) | mgl-1 | inconclusive | / | / | / | 6,42 | 5,95 | 5,83 | 5,56 | 4,47 | inconclusive | 5,6 |
| Ammonium - ion NH4+ | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrite NO2- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrate NO3- | mgl-1 | / | 2,35 | 2,96 | / | <1 | <1 | <1 | 2,58 | 2,03 | 3,47 | |
| Nitrate nitrogen (NO3-N) | mgl-1 | / | 0,53 | 0,67 | / | / | / | / | 0,58 | 0,46 | 0,78 | 0,6 |
| Phosphate PO43- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Sulphate SO42- | mgl-1 | / | 7,6 | 7,72 | / | 6,15 | 8,7 | 7,57 | 6,98 | 6,3 | 7,79 | 7,35 |
| Chloride Cl- | mgl-1 | / | 4,95 | 26,9 | / | 2,47 | 3,33 | 2,98 | 2,04 | 2,4 | 2,49 | 5,9 |
| Fluoride F- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Bromide Br- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| | | | | | | | | | | | | |
| Sodium Na+ | mgl-1 | / | / | / | / | 2,45 | 3,52 | 3,71 | 2,34 | 2,81 | 2,67 | 2,9 |
| Potassium K+ | mgl-1 | / | / | / | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Magnesium Mg 2+ | mgl-1 | / | / | / | / | 2,2 | 2,91 | 3,12 | 2,55 | 2,73 | 2,49 | 2,6 |
| Calcium Ca 2+ | mgl-1 | / | / | / | / | 28,6 | 34,5 | 43,1 | 35,4 | 36,7 | 48,2 | 37,75 |
| | | | | | | | | | | | | |
| Toxicity analyses *(Vibrio fisheri)* | % | / | / | / | / | / | -9,86 | / | 25,82 | / | / | |

### *Appendix 2.9: Table of data and results of measured variables at VOG-J6 location*

**sample VOG-J6 (upper basin)** **Physical - Chemical analyses**

| **Variable** | **Unit** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14.3.2010 | 3.4.2010 | 6.6.2010 | 17.6.2010 | 21.7.2010 | 11.8.2010 | 5.9.2010 | 28.9.2010 | 23.10.2010 | 20.11.2010 | |
| notes | | | | | | | | | | | turbid water | |
| time/weather | | 10:34/sunny | 11:02/sunny | 10:15/sunny | / | 13:05/sunny | 12:45/clear | 12:40/cloudy | 12:55/cloudy | 12:32/cloudy | 12:05/cloudy | |
| T air | oC | 15,4 | 13,4 | 24,5 | / | 29 | 28,8 | 22 | 17 | 16 | 14,6 | |
| T water | oC | 5,8 | 12,5 | 21,6 | / | 29,3 | 28,3 | 22,3 | 16,4 | 13 | 12,7 | |
| pH | | 8,6 | 8,49 | 7,77 | / | 8,19 | 8,26 | 8,11 | 8,12 | 7,99 | 7,96 | 8,2 |
| Electrical conductivity (EC) | µScm-1 | 347 | 333 | 335 | / | 293 | 251 | 322 | 341 | 392 | 389 | 334 |
| Oxygen concentration | mgl-1 | / | / | / | / | / | 8,1 | 7,95 | 8,1 | 6,42 | 6,51 | 7,4 |
| Oxygen saturation | % | / | / | / | / | / | 103 | 91,9 | 83,8 | 61,2 | 51,8 | 78,3 |
| Colour | | none | none | none | / | none | none | none | arly pale yellow | none | none | |
| COD | mgl-1 | 5 | 5 | 10 | / | 10 | 11,6 | 12 | 13 | 8 | 9 | 9,3 |
| BOD5 | mgl-1 | / | / | <2 | / | / | 5,9 | 3,1 | / | 3,6 | 2,2 | |
| Total Carbon (TC) | mgl-1 | inconclusive | / | / | / | 38,34 | 32,38 | 39,8 | 42,67 | 46,88 | inconclusive | |
| Total Organic Carbon (TOC) | mgl-1 | inconclusive | / | / | / | 6,18 | 6,21 | 5,55 | 6,26 | 3,54 | inconclusive | 5,5 |
| Ammonium - ion NH4+ | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrite NO2- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrate NO3- | mgl-1 | / | 2,8 | 2,6 | / | <1 | <1 | <1 | 2,31 | 2,03 | 3,54 | |
| Nitrate nitrogen (NO3-N) | mgl-1 | / | 0,63 | 0,59 | / | / | / | / | 0,52 | 0,46 | 0,8 | 0,6 |
| Phosphate PO43- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Sulphate SO42- | mgl-1 | / | 10,4 | 7,58 | / | 6,96 | 8,6 | 7,62 | 6,8 | 6,46 | 9,48 | 8 |
| Chloride Cl- | mgl-1 | / | 6,59 | 2,36 | / | 3,01 | 3,33 | 3,01 | 1,92 | 2,47 | 2,51 | 3,15 |
| Fluoride F- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Bromide Br- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| | | | | | | | | | | | | |
| Sodium Na+ | mgl-1 | / | / | / | / | 3 | 3,49 | 3,71 | 2,12 | 2,79 | 2,81 | 3 |
| Potassium K+ | mgl-1 | / | / | / | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Magnesium Mg 2+ | mgl-1 | / | / | / | / | 2,6 | 2,84 | 3,11 | 2,51 | 2,75 | 3,19 | 2,8 |
| Calcium Ca 2+ | mgl-1 | / | / | / | / | 28,4 | 32,7 | 42,5 | 35,9 | 37,9 | 53,8 | 38,5 |
| | | | | | | | | | | | | |
| Toxicity analyses *(Vibrio fisheri)* | % | / | / | / | / | / | -3,66 | / | 21,42 | / | / | |

***Appendix 2.10: Table of data and results of measured variables at VOG-J7 location***

**sample VOG-J7 (upper basin)** **Physical - Chemical analyses**

| **Variable** | **Unit** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14.3.2010 | 3.4.2010 | 6.6.2010 | 17.6.2010 | 21.7.2010 | 11.8.2010 | 5.9.2010 | 28.9.2010 | 23.10.2010 | 20.11.2010 | |
| notes | | | | | | | | | | | | |
| time/weather | | 12:45/sunny | 13:00/cloudy | 13:20/sunny | / | 15:45/sunny | 16:00/clear | 15:45/cloudy | 16:05/cloudy | 15:30/cloudy | 14:40/cloudy | |
| T air | oC | 15,1 | 17 | 28,8 | / | 28,8 | 28,4 | 22,8 | 17 | 15 | 14,2 | |
| T water | oC | 6,5 | 12,8 | 24,7 | / | 29,6 | 29,2 | 22 | 16,8 | 13 | 12,8 | |
| pH | | 8,41 | 8,52 | 8,18 | / | 8,24 | 8,28 | 8,25 | 8,05 | 7,8 | 7,91 | 8,2 |
| Electrical conductivity (EC) | µScm-1 | 346 | 330 | 325 | / | 294 | 255 | 326 | 334 | 392 | 381 | 331 |
| Oxygen concentration | mgl-1 | / | / | / | / | / | 7,2 | 7,6 | 6,1 | 6,45 | 6,33 | 6,7 |
| Oxygen saturation | % | / | / | / | / | / | 94,8 | 87,2 | 63,6 | 61,9 | 60,6 | 73,6 |
| Colour | | none | none | none | / | none | none | none | pale yellow | ery pale jellow | none | |
| COD | mgl-1 | <5 | 6 | 9,3 | / | 11 | 12 | 12,3 | 11 | 7 | 9 | 9,7 |
| BOD5 | mgl-1 | / | <2 | <2 | / | 4,2 | / | / | / | / | / | |
| Total Carbon (TC) | mgl-1 | inconclusive | / | / | / | 37,18 | 32,83 | 38,56 | 42,45 | 48,4 | inconclusive | |
| Total Organic Carbon (TOC) | mgl-1 | inconclusive | / | / | / | 5,46 | 6,06 | 4,57 | 5,95 | 4,82 | inconclusive | 5,4 |
| Ammonium - ion NH4+ | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrite NO2- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrate NO3- | mgl-1 | / | 2,59 | 2,9 | / | <1 | <1 | <1 | 2,43 | 2,08 | 3,56 | |
| Nitrate nitrogen (NO3-N) | mgl-1 | / | 0,58 | 0,65 | / | / | / | / | 0,55 | 0,47 | 0,8 | 0,61 |
| Phosphate PO43- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Sulphate SO42- | mgl-1 | / | 10,9 | 7,63 | / | 7,22 | 8,2 | 7,65 | 6,51 | 6,5 | 8,58 | 7,9 |
| Chloride Cl- | mgl-1 | / | 4,62 | 3,91 | / | 2,96 | 3,29 | 3,1 | 1,92 | 2,44 | 2,45 | 3,1 |
| Fluoride F- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Bromide Br- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| | | | | | | | | | | | | |
| Sodium Na+ | mgl-1 | / | / | / | / | 2,97 | 3,4 | 3,73 | 2,33 | 2,87 | 2,77 | 3 |
| Potassium K+ | mgl-1 | / | / | / | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Magnesium Mg 2+ | mgl-1 | / | / | / | / | 2,61 | 2,82 | 3,12 | 2,73 | 2,79 | 3,02 | 2,8 |
| Calcium Ca 2+ | mgl-1 | / | / | / | / | 37,8 | 27,8 | 42,7 | 29 | 40,3 | 44,6 | 37 |
| | | | | | | | | | | | | |
| Toxicity analyses *(Vibrio fisheri)* | % | / | / | / | / | / | 4,62 | / | 8,96 | / | / | |

## *Appendix 2.11: Table of data and results of measured variables at VOG-J8 location*

**sample VOG-J8 (main basin)** **Physical - Chemical analyses**

| **Variable** | **Unit** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14.3.2010 | 3.4.2010 | 6.6.2010 | 17.6.2010 | 21.7.2010 | 11.8.2010 | 5.9.2010 | 28.9.2010 | 23.10.2010 | 20.11.2010 | |
| notes | | | | | | | | | | | | |
| time/weather | | 14:32/sunny | 14:34/cloudy | 15:03/sunny | / | 9:22/sunny | 9:33/clear | 9:20/cloudy | 9:40/cloudy | 9:10/cloudy | 9:00/cloudy | |
| T air | oC | 15,8 | 16 | 29 | / | 25,4 | 26,5 | 19 | 16 | 17 | 12 | |
| T water | oC | 6,1 | 11,3 | 24 | / | 28,1 | 26,4 | 22,2 | 18,7 | 14,7 | 12,4 | |
| pH | | 8,22 | 8,35 | 8,24 | / | 8,29 | 8,24 | 7,89 | 7,88 | 8,17 | 7,84 | 8,1 |
| Electrical conductivity (EC) | µScm-1 | 298 | 302 | 217 | / | 242 | 230 | 240 | 245 | 270 | 285 | 259 |
| Oxygen concentration | mgl-1 | / | / | / | / | / | 8,8 | 6,34 | 6,2 | 6,45 | 6,3 | 6,8 |
| Oxygen saturation | % | / | / | / | / | / | 109 | 73,1 | 67,4 | 63,8 | 59,5 | 74,6 |
| Colour | | none | none | none | / | none | none | none | none | ery pale jellow | none | |
| COD | mgl-1 | 7 | 5,6 | 9 | / | 10 | 12 | 13 | 9,5 | 8 | 10 | 9,3 |
| BOD5 | mgl-1 | / | / | <2 | / | / | 2 | <2 | / | <2 | / | |
| Total Carbon (TC) | mgl-1 | inconclusive | / | / | / | 30,82 | 27,2 | 26,07 | 28,48 | 30,56 | inconclusive | |
| Total Organic Carbon (TOC) | mgl-1 | inconclusive | / | / | / | 5,66 | 5,49 | 3,99 | 4,88 | 4,22 | inconclusive | 4,8 |
| Ammonium - ion NH4+ | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrite NO2- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrate NO3- | mgl-1 | / | 3,63 | 2,36 | / | 1,53 | 1,1 | <1 | 1,53 | 1,51 | 2,32 | |
| Nitrate nitrogen (NO3-N) | mgl-1 | / | 0,82 | 0,53 | / | 0,34 | 0,25 | / | 0,34 | 0,34 | 0,52 | 0,45 |
| Phosphate PO43- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Sulphate SO42- | mgl-1 | / | 10,4 | 12,3 | / | 12,3 | 12,4 | 11,8 | 10,6 | 9,62 | 10,8 | 11,3 |
| Chloride Cl- | mgl-1 | / | 5,09 | 4,5 | / | 4,54 | 4,26 | 3,93 | 3,58 | 3,35 | 3,37 | 4 |
| Fluoride F- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Bromide Br- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| | | | | | | | | | | | | |
| Sodium Na+ | mgl-1 | / | / | / | / | 3,65 | 3,5 | 3,67 | 3,02 | 3,09 | 2,97 | 3,3 |
| Potassium K+ | mgl-1 | / | / | / | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Magnesium Mg 2+ | mgl-1 | / | / | / | / | 3,54 | 3,31 | 3,46 | 3,11 | 3,16 | 3,16 | 3,3 |
| Calcium Ca 2+ | mgl-1 | / | / | / | / | 35,8 | 29,8 | 32,7 | 26,2 | 29,6 | 37,8 | 32 |
| | | | | | | | | | | | | |
| Toxicity analyses *(Vibrio fisheri)* | % | / | / | / | / | / | -1,7 | / | 4,98 | / | / | |

### *Appendix 2.12: Table of data and results of measured variables at VOG-J9 location*

| **sample VOG-J9 (main basin)** | | | | **Physical - Chemical analyses** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Location 1 | Location 2 | Location 2 | Location 2 | Location 2 | Location 2 | Location 2 | Location 2 | Location 2 | Location 2 | |
| **Variable** | **Unit** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Average** |
| | | 14.3.2010 | 3.4.2010 | 6.6.2010 | 17.6.2010 | 21.7.2010 | 11.8.2010 | 5.9.2010 | 28.9.2010 | 23.10.2010 | 20.11.2010 | |
| notes | | | | | | | | | | | | |
| time/weather | | 14:02/sunny | 15:14/cloudy | 15:40/sunny | / | 8:20/sunny | 8:40/clear | 8:32/cloudy | 8:53/cloudy | 8:25/cloudy | 8:30/cloudy | |
| T air | oC | 15,2 | 17 | 29 | / | 25 | 23,5 | 17,8 | 15 | 15 | 10 | |
| T water | oC | 8,9 | 13,1 | 28 | / | 27,7 | 26,3 | 22 | 19 | 14,6 | 12,3 | |
| pH | | 7,85 | 8,25 | 8,29 | / | 8 | 8,12 | 7,91 | 7,87 | 7,73 | 7,76 | 8 |
| Electrical conductivity (EC) | µScm-1 | 317 | 302 | 275 | / | 245 | 241 | 239 | 251 | 271 | 288 | 270 |
| Oxygen concentration | mgl-1 | / | / | / | / | / | 8,8 | 6,5 | 5,7 | 5,02 | 6,73 | 6,5 |
| Oxygen saturation | % | / | / | / | / | / | 109 | 75 | 62,2 | 49,6 | 63,3 | 71,8 |
| Colour | | none | none | none | / | none | none | none | none | none | none | |
| COD | mgl-1 | 6 | 6 | 9 | / | 11 | 12 | 11,3 | 11,5 | 8 | 12 | 9,6 |
| BOD5 | mgl-1 | / | / | <2 | / | 2,8 | / | / | / | / | 2,4 | |
| Total Carbon (TC) | mgl-1 | inconclusive | / | / | / | 30,63 | 28,78 | 26,66 | 29 | 31,15 | inconclusive | |
| Total Organic Carbon (TOC) | mgl-1 | inconclusive | / | / | / | 5,4 | 5,63 | 4,71 | 4,89 | 4,48 | inconclusive | 5 |
| Ammonium - ion $NH_4^+$ | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrite $NO_2^-$ | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrate $NO_3^-$ | mgl-1 | / | 3,63 | 2,59 | / | 1,6 | 1,2 | <1 | 1,46 | 1,45 | 2,61 | |
| Nitrate nitrogen ($NO_3$-N) | mgl-1 | / | 0,82 | 0,58 | / | 0,36 | 0,27 | / | 0,33 | 0,33 | 0,59 | 0,47 |
| Phosphate $PO_4^{3-}$ | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Sulphate $SO_4^{2-}$ | mgl-1 | / | 12,4 | 11,6 | / | 11,6 | 13,2 | 12,1 | 11,3 | 9,74 | 11,8 | 11,7 |
| Chloride $Cl^-$ | mgl-1 | / | 6,09 | 5,75 | / | 4,96 | 4,51 | 3,99 | 3,78 | 3,34 | 3,46 | 4,5 |
| Fluoride $F^-$ | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Bromide $Br^-$ | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| | | | | | | | | | | | | |
| Sodium $Na^+$ | mgl-1 | / | / | / | / | 3,67 | 3,74 | 3,68 | 3,28 | 3,03 | 3,14 | 3,4 |
| Potassium $K^+$ | mgl-1 | / | / | / | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Magnesium $Mg^{2+}$ | mgl-1 | / | / | / | / | 3,23 | 3,57 | 3,52 | 3,35 | 3,16 | 3,56 | 3,4 |
| Calcium $Ca^{2+}$ | mgl-1 | / | / | / | / | 26,5 | 32,4 | 31,4 | 28,6 | 29,4 | 42,2 | 31,75 |
| | | | | | | | | | | | | |
| Toxicity analyses *(Vibrio fisheri)* | % | / | / | / | / | / | -7,3 | / | 7,26 | / | / | |

### *Appendix 2.13: Table of data and results of measured variables at VOG-D1 location*

**sample VOG-D1 (Dolenjski potok stream; running water)** **Physical - Chemical analyses**

| Variable | Unit | Date | Date | Date | Date | Date | Date | Date | Date | Date | Date | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14.3.2010 | 3.4.2010 | 6.6.2010 | 17.6.2010 | 21.7.2010 | 11.8.2010 | 5.9.2010 | 28.9.2010 | 23.10.2010 | 20.11.2010 | |
| notes | | | | | | | | low flow | | | high flow | |
| time/weather | | 13:25/sunny | 13:50/sunny | 14:03/sunny | / | 16:15/sunny | 16:55/clear | 16:25/cloudy | 16:45/cloudy | 16:10/cloudy | 15:15/cloudy | |
| T air | oC | 17,8 | 15,8 | 25 | / | 28 | 21,5 | 21 | 17 | 14 | 13 | |
| T water | oC | 12,4 | 12,5 | 14,2 | / | 17,7 | 17,4 | 15,8 | 14 | 12,8 | 12,6 | |
| pH | | 8,26 | 8,28 | 8,07 | / | 8,05 | 7,95 | 8,15 | 7,83 | 7,95 | 8,04 | 8,1 |
| Electrical conductivity (EC) | µScm-1 | 328 | 407 | 335 | / | 356 | 376 | 381 | 393 | 367 | 401 | 371 |
| Oxygen concentration | mgl-1 | / | / | / | / | / | 7,85 | 7,57 | 7,4 | 9,53 | 8,45 | 8,2 |
| Oxygen saturation | % | / | / | / | / | / | 82,8 | 77,1 | 72,9 | 90,9 | 80,5 | 80,8 |
| Colour | | none | none | none | / | none | none | none | none | none | none | |
| COD | mgl-1 | 6 | 4 | 3 | / | 4 | 3,6 | 5,5 | 6,4 | 5 | 5 | 4,7 |
| BOD5 | mgl-1 | / | / | / | / | / | / | / | / | / | / | |
| Total Carbon (TC) | mgl-1 | inconclusive | / | / | / | 39,8 | 43,73 | 42,31 | 47,42 | 42,83 | inconclusive | |
| Total Organic Carbon (TOC) | mgl-1 | inconclusive | / | / | / | 2,46 | 3,73 | 3,21 | 4 | 3,46 | inconclusive | 3,4 |
| Ammonium - ion NH4+ | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrite NO2- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrate NO3- | mgl-1 | / | 4,52 | 3,84 | / | 5,39 | 6,7 | 6,1 | 4,49 | 5,32 | 5,1 | |
| Nitrate nitrogen (NO3-N) | mgl-1 | / | 1,02 | 0,87 | / | 1,22 | 1,51 | 1,38 | 1,01 | 1,2 | 1,15 | 1,17 |
| Phosphate PO43- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Sulphate SO42- | mgl-1 | / | 7,8 | 4,74 | / | 5,24 | 7,2 | 7,31 | 6,75 | 6,11 | 7,65 | 6,6 |
| Chloride Cl- | mgl-1 | / | 4,82 | 2,27 | / | 3,29 | 4,09 | 3,77 | 2,49 | 2,99 | 2,52 | 3,3 |
| Fluoride F- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Bromide Br- | mgl-1 | / | <1 | <1 | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| | | | | | | | | | | | | |
| Sodium Na+ | mgl-1 | / | / | / | / | 2,85 | 3,85 | 4,14 | 2,62 | 3,02 | 2,82 | 3,2 |
| Potassium K+ | mgl-1 | / | / | / | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Magnesium Mg 2+ | mgl-1 | / | / | / | / | 1,53 | 2,03 | 2,13 | 2,28 | 2,05 | 2,38 | 2 |
| Calcium Ca 2+ | mgl-1 | / | / | / | / | 38,8 | 39,6 | 50,1 | 38,2 | 32,2 | 52,2 | 41,85 |
| | | | | | | | | | | | | |
| Toxicity analyses *(Vibrio fisheri)* | % | / | / | / | / | / | -3,1 | / | 9,1 | / | / | |

## *Appendix 2.14: Table of data and results of measured variables at VOG-D2 location*

**sample VOG-D2 (melioration ditch; stagnant water)** **Physical - Chemical analyses**

| **Variable** | **Unit** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14.3.2010 | 3.4.2010 | 6.6.2010 | 17.6.2010 | 21.7.2010 | 11.8.2010 | 5.9.2010 | 28.9.2010 | 23.10.2010 | 20.11.2010 | |
| notes | | | | | | dry channel | | | | | very slow flow | |
| time/weather | | 8:47/sunny | 8:30/sunny | 7:43/sunny | / | / | 10:45/clear | 10:03/cloudy | 10:35/cloudy | 10:12/cloudy | 10:00/cloudy | |
| T air | oC | 7 | 8,1 | 18,2 | / | / | 25,6 | 19 | 17 | 14 | 12,5 | |
| T water | oC | 3,5 | 8,2 | 15,6 | / | / | 19,1 | 14,6 | 16,6 | 9 | 12,3 | |
| pH | | 7,92 | 8,17 | 7,69 | / | / | *7,28 | *7,2 | 7,37 | 7,67 | 7,64 | 7,6 |
| Electrical conductivity (EC) | µScm-1 | 409 | 377 | 441 | / | / | *671 | *625 | 370 | 527 | 387 | 476 |
| Oxygen concentration | mgl-1 | / | / | / | / | / | *3,5 | *3,15 | 6,62 | 6,75 | 8,2 | 5,6 |
| Oxygen saturation | % | / | / | / | / | / | *39 | *31,2 | 68,7 | 59 | 76,3 | 54,8 |
| Colour | | none | none | none | / | / | none | none | irly pale jellow | none | none | |
| COD | mgl-1 | 6 | 5,3 | 6 | / | / | 9 | 10 | 8 | 6 | 9 | 7,4 |
| BOD5 | mgl-1 | / | / | / | / | / | 6 | <2 | / | / | 2,5 | |
| Total Carbon (TC) | mgl-1 | inconclusive | / | / | / | / | 77,41 | 79,66 | 44,25 | 64,53 | inconclusive | |
| Total Organic Carbon (TOC) | mgl-1 | inconclusive | / | / | / | / | 13,51 | 12,76 | 5,43 | 4,74 | inconclusive | 9,1 |
| Ammonium - ion NH4+ | mgl-1 | / | <1 | <1 | / | / | <1 | <1 | <1 | <1 | <1 | |
| Nitrite NO2- | mgl-1 | / | <1 | <1 | / | / | <1 | <1 | <1 | <1 | <1 | |
| Nitrate NO3- | mgl-1 | / | 4,37 | <1 | / | / | <1 | <1 | 1,79 | <1 | 2,92 | |
| Nitrate nitrogen (NO3-N) | mgl-1 | / | 0,99 | / | / | / | / | / | 0,38 | / | 0,66 | 0,68 |
| Phosphate PO43- | mgl-1 | / | <1 | <1 | / | / | <1 | <1 | <1 | <1 | <1 | |
| Sulphate SO42- | mgl-1 | / | 18,6 | 18,4 | / | / | 12,4 | 3,27 | 13,8 | 9,8 | 16,6 | 15,3 |
| Chloride Cl- | mgl-1 | / | 4,5 | 3,59 | / | / | 2,09 | 2,18 | 2,34 | 3,7 | 2,62 | 3,1 |
| Fluoride F- | mgl-1 | / | <1 | <1 | / | / | <1 | <1 | <1 | <1 | <1 | |
| Bromide Br- | mgl-1 | / | <1 | <1 | / | / | <1 | <1 | <1 | <1 | <1 | |
| | | | | | | | | | | | | |
| Sodium Na+ | mgl-1 | / | / | / | / | / | 9,13 | 7,82 | 4,61 | 8,26 | 4,6 | 6,9 |
| Potassium K+ | mgl-1 | / | / | / | / | / | <1 | <1 | <1 | <1 | <1 | |
| Magnesium Mg 2+ | mgl-1 | / | / | / | / | / | 9,24 | 8,79 | 5,21 | 6,54 | 5,2 | 7 |
| Calcium Ca 2+ | mgl-1 | / | / | / | / | / | 70 | 72,8 | 32,6 | 45,7 | 50,2 | 54,3 |
| | | | | | | | | | | | | |
| Toxicity analyses *(Vibrio fisheri)* | % | / | / | / | / | / | -0,44 | 18,46 | 6,74 | / | 10,4 | |

*low water level; WTW held in diagonal

## *Appendix 2.15: Table of data and results of measured variables at VOG-L1 location*

**sample VOG-L1 (melioration ditch; stagnant water)** **Physical - Chemical analyses**

| **Variable** | **Unit** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14.3.2010 | 3.4.2010 | 6.6.2010 | 17.6.2010 | 21.7.2010 | 11.8.2010 | 5.9.2010 | 28.9.2010 | 23.10.2010 | 20.11.2010 | |
| notes | | | | | | dry channel | | | | | manure odour | |
| time/weather | | 11:26/sunny | 11:42/sunny | 11:15/sunny | / | / | 14:00/clear | 13:42/cloudy | 14:05/cloudy | 13:42/cloudy | 13:00/cloudy | |
| T air | oC | 12,8 | 17,4 | 24,9 | / | / | 23,1 | 22 | 16 | 15 | 14,8 | |
| T water | oC | 5,4 | 10,4 | 16 | / | / | 18,3 | 15 | 16,1 | 10,7 | 13 | |
| pH | | 7,88 | 8,04 | 7,72 | / | / | 7,32 | 7,75 | 7,71 | 7,6 | 8,02 | 7,7 |
| Electrical conductivity (EC) | µScm-1 | 466 | 465 | 496 | / | / | 550 | 537 | 487 | 691 | 515 | 526 |
| Oxygen concentration | mgl-1 | / | / | / | / | / | 1,2 | 1,1 | 6,82 | 2,85 | 7,8 | 3,9 |
| Oxygen saturation | % | / | / | / | / | / | 12,7 | 10,7 | 70,2 | 25,7 | 74,8 | 38,8 |
| Colour | | none | none | none | / | / | none | none | pale jellow | none | none | |
| COD | mgl-1 | <5 | 4,6 | 4,6 | / | / | 9 | 10 | 8,5 | 7 | 7 | 7,2 |
| BOD5 | mgl-1 | / | / | / | / | / | 5,4 | / | / | 2,9 | <2 | |
| Total Carbon (TC) | mgl-1 | inconclusive | / | / | / | / | 67,51 | 63,97 | inconclusive | 63,57 | inconclusive | |
| Total Organic Carbon (TOC) | mgl-1 | inconclusive | / | / | / | / | 5,53 | 5,33 | inconclusive | 4,6 | inconclusive | 5,1 |
| Ammonium - ion NH4+ | mgl-1 | / | <1 | <1 | / | / | <1 | <1 | <1 | <1 | <1 | |
| Nitrite NO2- | mgl-1 | / | <1 | <1 | / | / | <1 | <1 | <1 | <1 | <1 | |
| Nitrate NO3- | mgl-1 | / | 6,73 | 3,36 | / | / | <1 | <1 | 2,97 | 1,7 | 3,57 | |
| Nitrate nitrogen (NO3-N) | mgl-1 | / | 1,51 | 0,76 | / | / | / | / | 0,67 | 0,38 | 0,81 | 0,83 |
| Phosphate PO43- | mgl-1 | / | <1 | <1 | / | / | <1 | <1 | <1 | <1 | <1 | |
| Sulphate SO42- | mgl-1 | / | 9,12 | 5,33 | / | / | 8,83 | 6,79 | 7,45 | 8,63 | 8,08 | 7,7 |
| Chloride Cl- | mgl-1 | / | 9,63 | 4,2 | / | / | 7,74 | 6,17 | 3,14 | 5,48 | 3,61 | 5,7 |
| Fluoride F- | mgl-1 | / | <1 | <1 | / | / | <1 | <1 | <1 | <1 | <1 | |
| Bromide Br- | mgl-1 | / | <1 | <1 | / | / | <1 | <1 | <1 | <1 | <1 | |
| | | | | | | | | | | | | |
| Sodium Na+ | mgl-1 | / | / | / | / | / | 7,06 | 6,79 | 3,68 | 6,46 | 3,81 | 5,6 |
| Potassium K+ | mgl-1 | / | / | / | / | / | <1 | <1 | <1 | <1 | <1 | |
| Magnesium Mg 2+ | mgl-1 | / | / | / | / | / | 4,29 | 4,57 | 3,16 | 4,45 | 2,97 | 3,9 |
| Calcium Ca 2+ | mgl-1 | / | / | / | / | / | 55,9 | 74,1 | 39,7 | 52,6 | 50,5 | 54,6 |
| | | | | | | | | | | | | |
| Toxicity analyses *(Vibrio fisheri)* | % | / | / | / | / | / | -5,62 | 15,9 | 13,22 | / | 12,3 | |

### *Appendix 2.16: Table of data and results of measured variables at VOG-L2a location*

**sample VOG-L2a (melioration ditch; stagnant water)** **Physical - Chemical analyses**

| **Variable** | **Unit** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Date** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14.3.2010 | 3.4.2010 | 6.6.2010 | 17.6.2010 | 21.7.2010 | 11.8.2010 | 5.9.2010 | 28.9.2010 | 23.10.2010 | 20.11.2010 | |
| notes | | | | | | | | | turbid water | * | | |
| time/weather | | 11:54/sunny | 12:14/sunny | 12:00/sunny | 0/changeable | 14:35/sunny | 14:49/clear | 14:30/cloudy | 14:51/cloudy | 14:25/cloudy | 13:35/cloudy | |
| T air | oC | 15,3 | 17,4 | 24,9 | 21,1 | 28,5 | 25,9 | 22,2 | 17 | 15 | 14,9 | |
| T water | oC | 7,3 | 10,1 | 14,7 | 16,6 | 22,6 | 20,4 | 15,9 | 16,2 | 9,6 | 13,3 | |
| pH | | 8,01 | 8,1 | 7,82 | 7,7 | 7,71 | 7,39 | 7,54 | 7,77 | 7,32 | 8,1 | 7,7 |
| Electrical conductivity (EC) | µScm-1 | 406 | 401 | 439 | 447 | 347 | 317 | 402 | 449 | 566 | 461 | 423 |
| Oxygen concentration | mgl-1 | / | / | / | / | / | 1,1 | 0,5 | 6,22 | 0,68 | 7,11 | 3,1 |
| Oxygen saturation | % | / | / | / | / | / | 12,7 | 5,1 | 64 | 6 | 68,6 | 31,3 |
| Colour | | none | none | none | none | none | none | none | none | ery pale brown | none | |
| COD | mgl-1 | 9 | 3 | 4,6 | 6 | 10,6 | 11 | 18 | 6 | 22 | 6 | 9,6 |
| BOD5 | mgl-1 | / | / | / | 3,4 | 3,4 | 5 | 2,4 | / | >7 | / | |
| Total Carbon (TC) | mgl-1 | inconclusive | / | / | / | 43,82 | 39,93 | 49,73 | inconclusive | 74,96 | inconclusive | |
| Total Organic Carbon (TOC) | mgl-1 | inconclusive | / | / | / | 5,9 | 5,52 | 5,19 | inconclusive | 16,08 | inconclusive | 8,2 |
| Ammonium - ion NH4+ | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrite NO2- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Nitrate NO3- | mgl-1 | / | 2,67 | 2,73 | 2,5 | <1 | <1 | <1 | 2,2 | <1 | 3,18 | |
| Nitrate nitrogen (NO3-N) | mgl-1 | / | 0,6 | 0,62 | 0,56 | / | / | / | 0,5 | / | 0,72 | 0,6 |
| Phosphate PO43- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Sulphate SO42- | mgl-1 | / | 3,36 | 4,94 | 3,29 | 4,44 | 6,34 | 4,71 | 3,39 | 6,09 | 3,21 | 4,4 |
| Chloride Cl- | mgl-1 | / | 3,86 | 3,59 | 3,81 | 2,41 | 3,49 | 3,67 | 2,42 | 4,18 | 2,41 | 3,3 |
| Fluoride F- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| Bromide Br- | mgl-1 | / | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | |
| | | | | | | | | | | | | |
| Sodium Na+ | mgl-1 | / | / | / | / | 2,14 | 3,31 | 3,52 | 2,37 | 4,66 | 2,59 | 3,1 |
| Potassium K+ | mgl-1 | / | / | / | / | <1 | <1 | <1 | <1 | <1 | <1 | |
| Magnesium Mg 2+ | mgl-1 | / | / | / | / | 1,91 | 2,58 | 2,76 | 1,5 | 3,05 | 1,45 | 2,2 |
| Calcium Ca 2+ | mgl-1 | / | / | / | / | 33,9 | 43,4 | 54,7 | 35,5 | 46,9 | 43,8 | 43 |
| | | | | | | | | | | | | |
| Toxicity analyses *(Vibrio fisheri)* | % | / | / | / | -3,44 | / | -11,84 | 6,98 | 11,9 | / | 17,68 | |

* tree leaves cover the channel bottom