Algorithm for Assessing Irrigation Water Use Potential Pertaining Present Water Protection Measures at the Danube and Adriatic Sea River Basins

Rozalija CVEJIC [1] (✉)
Jana MELJO [2]
Marina PINTAR [1]

Summary

The approach for developing a sectoral water use demand plan for irrigation sector is represented in this paper. The aim of the research is to inform implementation of the measure DDU26 set out by the River basin management plan for the Danube and Adriatic Sea river basins. The latter is an umbrella operational plan set out to achieve good status of water bodies under the EU Water Framework Directive (WFD).

The aim of the measure DDU26 is to estimate (a) available stocks of surface water and groundwater and (b) existing and projected water use for the period until 2021. To achieve this all water use sectors (irrigation, domestic use, cooling in electricity production, process water in industry, tourism, etc.) need to establish their own water demand plans reflecting their sectoral development programmes.

Projections of future irrigation water use show the current water use for irrigation will increase. However no spatial reference on where this development will happen is defined thus the projection poorly informs the DDU26 implementation.

To overpass the sectoral gap and inform spatially weighted irrigation development that relates to water source use potential pertaining current protection aspirations under the River Basin Management Plan (RBMP), we document the development of the irrigation water use potential algorithm (IWUP). IWUP is a decision tree that helps choose best suitable irrigation water source of several available. The water sources use suitability is ranked on a scale from highly suitable for use to least suitable for use. Use priority of water sources for irrigation decreases accordingly: surface water stream, reservoir, and groundwater. The IWUP incorporates the WFD relevant variables such as ecologically acceptable flow of surface water streams, quantitative groundwater body status, and multifunctional reservoir use.

Key words

irrigation; water use; decision making

[1] University of Ljubljana, Biotechnical faculty, Centre for Agricultural Land Management and Agrohydrology, Jamnikarjeva 101, 1000 Ljubljana, Slovenia
✉ e-mail: rozalija.cvejic@bf.uni-lj.si
[2] Institute for Water, Republic of Slovenia, Hajdrihova c. 28c, 1000 Ljubljana, Slovenia

Received: May 15, 2013 | Accepted: February 19, 2014

ACKNOWLEDGEMENTS
The authors would like to express gratitude to the Ministry of Agriculture, Forestry and Food, and the Ministry for Research and Higher Education of the Republic of Slovenia for the financial support within the Target Research Programme project number V4-0487.

Introduction

The Water Framework Directive (WFD) is set to promote sustainable water use based on a long-term protection of available water resources. Operational plans to help implement the aim are RBMPs. These encompass programmes of measures which EU Member States are obliged to prepare for each (part of international) river basin district. Each programme includes a set of basic measures and, where necessary, supplementary measures. Within the Slovenian RBMP for the Danube and Adriatic Sea basin districts the promotion of sustainable water use based on a long-term protection of available water resources is required by the supplementary measure DDU26 (RBMP, 2011).

The aim of the measure DDU26 is to estimate (a) available stocks of groundwater and (b) existing and projected water use for the period until 2021. To achieve this all water use sectors (irrigation, domestic use, cooling in electricity production, process water in industry, tourism, etc.) need to establish their own water demand plans reflecting their sectoral development programmes. These will then be spatially aggregated and cross-checked for soundness regarding water protection measures and water use potentials of water bodies. The focus of this paper is preparation of water demand plan for irrigation sector.

Slovenian Ministry for Agriculture and Environment is adamant to maximise vegetable production to achieve higher market self-supply with vegetables. Growing vegetables inevitably involves irrigation and consequent building of new irrigation systems. Experience shows that large irrigation systems (LIS) (200-500 ha), used by several users (up to 200) enable efficient water use (one abstraction site, controlled water abstractions) and enable low operational costs of water supply and maintenance.

In the new programme period of Rural Development Programme (RDP) 2014-2020 the government plans to implement 4000 ha of new LIS. Projections of future irrigation water use show current water use for irrigation will increase. However the RDP does not provide any spatial reference on where this development will happen thus it fails to inform the DDU26 implementation. We document an attempt to overpass this sectoral gap and inform spatially weighted irrigation development that relates to water source use potential pertaining current protection aspirations under the RBMP. We document development of the irrigation water use potential algorithm (IWUP) that is an applicable decision making tool. Apart from its national relevance the tool development also has international relevance as it is applicable across administrative boundaries.

Materials and methods

Figure 1 shows the IWUP is a decision tree that helps choose best suitable irrigation water source of several available. The water sources use suitability is ranked on a scale from highly suitable for use (1) to least suitable for use (4). Use priority of water sources for irrigation decreases accordingly: surface water stream, reservoir, groundwater and wastewater. Existing reservoirs have higher irrigation use suitability compared to groundwater. Both have lower use priority for irrigation than the surface water stream, if the distance between LIS and surface water stream is less than 4 km horizontal distance. If the distance is greater, then building new reservoir or using water from the existing is economically more sensible. At horizontal distances greater than 6 km water demand for LIS implementation should be directed to groundwater sources. Generally wastewater has the lowest irrigation use priority (monitoring of chemical suitability, part of surface water stream balance, special storing needs). Irrigation water demand should be directed to its use only at distances greater than 3 km when all other considered water sources are unavailable.

Economic use suitability

Figure 1 shows economic use suitability spatially depends on horizontal distance (km) between potentially irrigable land and surface water stream. The dependence is derived from current terms and conditions for acquiring public funds to finance LIS implementation in Slovenia. These define the maximum project costs for LIS implementation must not exceed € 1.5 MM (€ 10 K ha^{-1}) (excl. VAT). Experience shows a 200 ha LIS requires 500 Φ mm water supply pipe and that its implementation represents 83 % of the LIS implementation costs. The calculation shows the implementation of a water supply pipe requires € 0.4 MM at 1 km distance, € 0.8 MM at 2 km and € 1.6 MM at 4 km distance and accounts for. The maximum suitable height difference from a

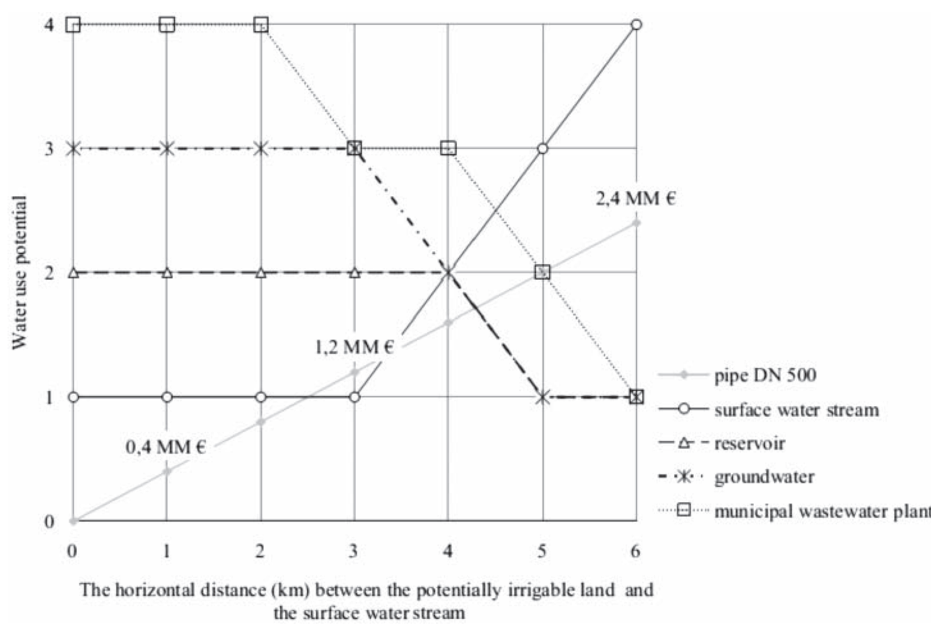

Figure 1. Irrigation water use potential algorithm ranks water sources from highly suitable for use (1) to least suitable for irrigation use (4). Priority of water sources for irrigation decreases accordingly: surface water stream, reservoir, groundwater and wastewater.

given surface water source to LIS, or to a point of water accumulation for later gravitational supply to lower lying LIS, is 100 m. If the current terms and conditions for acquiring public funds to finance LIS are taken into account, these are disproportionally high already after three kilometres horizontal and hundred meter height difference between the irrigation complex and the surface water source. Priority of using surface water bodies as an irrigation source for LIS drastically decreases with increasing water transport costs.

Surface water streams

Rules on determination and classification for water bodies on surface water define stand-alone surface water bodies (rivers with a catchment area of more than 100 km^2, a natural lake with a surface area greater than 0.5 km^2, artificial channels of more than 3 km, and water reservoirs on rivers and artificial lakes with a surface area greater than 0.5 km^2) (Official Gazette No 97/2009). There are 155 such water bodies at the territory of Slovenia.

To retain good surface water status under the WFD means to retain both good ecological and good chemical status. Decree on surface water status (Official Gazette No 14/2009, 98/2010) defines criteria for determining the status of surface waters, including ecological status. However there is no methodology developed to estimate the influence of irrigation water use on ecological status of a water body. The closest approximation that could be used is empirically defined Ecologically Acceptable Flow: a product of the Mean Annual Discharge in a period (daily average) and the watershed characteristics (factor f). Factor f depends on the (a) ecological body type, (b) catchment size, (c) abstraction rate and time of its occurrence, (d) and the ratio between the Mean Annual Flow and the Mean Annual Discharge in a period (daily average) (Official Gazette No 97/2009).

Characteristic flows are defined using hydrological data for the period 1971-2000. If the monitored data is unobtainable, the Mean Annual Discharge in period (daily average) estimation is possible through correlation (similar-watersheds approach). The watershed area and the measured flow at the monitoring network are paralleled with the watershed area and the flow at the surface water body end node. The calculation was applied to monthly flows within the growth season.

Potentially Available Flow represents the difference between the Most Probable Mean Dry Year Flow at the point of abstraction and the Ecologically Acceptable Flow. Each watershed level flow-duration-curve analysis includes 360 average monthly flow values (12 months, 30 year period). Minimum Periodic Mean Monthly Flow (May-September) (5 months, 30 year period) increased for the empirical factor 1.5, represents a 95 % occurrence of average monthly flow. Most Probable Mean Dry Year Flow for heavily modified and artificial water bodies was determined based on the hydropower concession agreements.

Reservoirs

The optimal reservoir impact area was assessed 360° around the reservoir within a 3 km distance and along the 3 km surface water stream buffer strip from the reservoir gate to the fork. The storage capacity was: predefined (using information provided by the asset management plans and reservoir managers), set experimentally (30 % of existing reservoir volume), or defined indirectly (the most probable water demand). Indirectly defined surface ratio between irrigated and non-irrigated cultures, grown on large irrigation systems, is 1:2.7 (Cvejić et al., 2010). In this context the most probable water demand is expressed with respect to 30 % of potentially irrigable land within the optimal reservoir impact area.

Groundwater

The groundwater use potential on the level of groundwater bodies was assessed with respect to the national groundwater use priority, availability and accessibility. Groundwater is protected as drinking water (Official Gazette No 67/2002) thus has lower use priority in respect to irrigation than surface water. Total yearly groundwater abstraction was estimated according to the groundwater fees data. The groundwater body recharge was assessed as a product between effective rainfall and the infiltration coefficient (Kennessy method) (Barazzuoli et al., 1986). It was assumed the quantitative status would not be endangered, if the ratio between estimated total yearly abstraction and aquifer recharge is below 33 % (RBMP, 2011).

Due to the knowledge gap regarding groundwater depth and thickness of saturated layer (RBMP, 2011), the porosity type and lithological structure data was used for defining spatial groundwater accessibility classes. High accessibility areas cover the main river alluvial plains with shallow water levels (less than 50 m depth), and high hydraulic conductivity (intergranular, alluvial aquifers). Medium accessibility areas cover karstic areas and Pliocene sandy gravel rocks that usually exchange with poorly permeable clay rocks. If drilling attempts have already not turned out unsuccessful (dry boreholes) they will most likely be deep (70 – 150 m). This increases later energy consumption. Low accessibility areas have low hydraulic conductivity and cover low permeable rocks such as Palaeozoic shale and sandstone, clay rocks, and igneous and metamorphic rocks. By abstracting groundwater from these aquifers (200 m depth), the water level decreases drastically.

Application area

The methodology of IWUP was applied using the national land use data for the year 2010 (1 m resolution orthophoto imagery) (Official Gazette No 122/2008). The area includes land use categories (a) arable land, (b) orchard plantations, (c) olive groves, (d) forest and other plantations, (e) permanent crops on arable land, (f) nurseries, and (g) hop fields. Potentially irrigable land assigned with these categories represents readily irrigated, experimentally irrigated, or land that could be irrigated. It covers 44 % (194,935 ha) of utilised agricultural land, which accounts for 9.6 % area of Slovenia. Irrigation water requirements for irrigation range from 0.56 $l\ s^{-1}\ ha^{-1}$ in the continental to 0.71 $l\ s^{-1}\ ha^{-1}$ in the mediterannean region.

Results with discussion

Surface water streams

Potentially suitable irrigable land within the surface water streams' impact area covers 125,964 ha of which 41.5 % (52,330 ha) could conditionally be supplied with the available surface water use potential. Direct abstraction of water for irrigation in the period May-September are not possible from 46 surface water streams, Q_{NET} is < 0.05 $m^3\ s^{-1}$ on 7 surface water streams, ≥ 0.05 < 1 $m^3\ s^{-1}$ on 22 surface water streams, ≥ 1 < 5 $m^3\ s^{-1}$ on

27 surface water streams and ≥ 5 <100 $m^3 s^{-1}$ on 18 surface water streams, respectively.

Two thirds of surface water streams show either negative irrigation use potential or limited irrigation use potential. LIS implementation at the impact areas of these surface water streams would need to involve building reservoirs for indirect water use for irrigation (accumulation during high waters off plant growth season) or should involve intense water demand management alongside the streams. In this sense building water use consensus along the stream and between the water use sectors is crucial and should be considered in the process of granting competing water rights. Developing LIS at these areas might endanger the potential of achieving good water body status under the RBMPs, however the areas might be of high importance for hosting small scale irrigation development (up to 10 ha).

A third of surface water streams show fairly good or very good irrigation water use potential. This indicates hot-spots for LIS development. It is highly unlikely that increased water abstraction for irrigation until 2021 at these areas would result in adverse environmental impact or endanger reaching good water body status under the RBMPs. Additionally these hot-spot areas should be of major interest for the government under the RDP 2014-2020 in terms of LIS development and organisation of vegetable growth production that would help achieve higher market self-supply with vegetables at the case study area (Figure 2).

Reservoirs

Eight out of 14 existing reservoirs built for storing irrigation water are used below the estimated potential of 10 MM m^3 (enough to supply 4,019 ha) while six, with the estimated potential 3.9 MM m^3 (1,550 ha) are not used for irrigation. The remaining 10 reservoirs, with the estimated potential 3 MM m^3 (1,201 ha), were neither built for nor are used for irrigation. The total water storage potential 16.9 MM m^3 (6,770 ha) is sufficient for 44 % of all potentially irrigable land at the impact area of the reservoirs. Reservoirs are used below their potentials even if primarily built for irrigation. Although they serve as flood protection infrastructure they still have the potential to serve other uses such as for storing irrigation water (Figure 2).

Prior to LIS development that would involve using the estimated water use potentials of existing reservoirs there is a need to officially establish their primary and define possible secondary uses of the existent secondary uses (legal or illegal, that evolved throughout the reservoir existence). This has been recognised as one of the priority measures under the measures DDU19 of

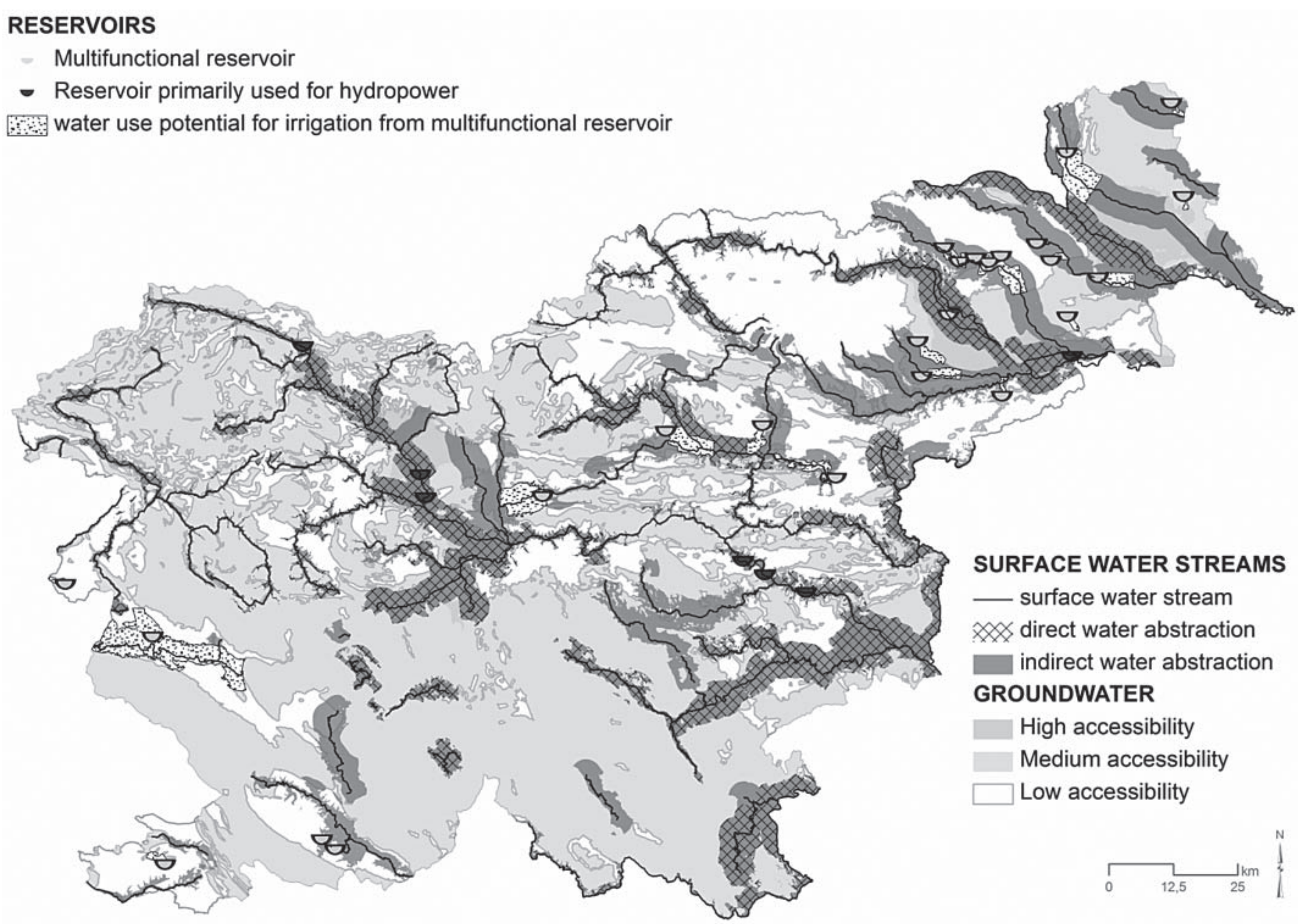

Figure 2. The water use potential map for irrigation at the Danube and Adriatic Sea river basins in Slovenia

the RBMP. However putting in order existing uses brings no real relevance to weighted irrigation development that relies on sectoral water use projections and water us potentials (DDU26).

Estimation of irrigation water use potentials of reservoirs will further need to involve implementation of the Article 48 of the Water Act (Official Gazette 67/2002) on the use of use of water infrastructure for other purposes (than built). This is possible if it is not in conflict with, or limits the exercise of the activity for which it was built. The use of water infrastructure for other the purposes involves obtaining the consent of the Ministry. Investor or person who intends to use the infrastructure for other purposes (for example municipalities investing in LIS) can be financially involved in the reconstruction of water infrastructure.

This research indicates reservoirs that could be of interest for such reconstruction to host storage volumes for storing irrigation water. This is important as increased use of reservoir potentials for irrigation would help improve water availability for irrigation at areas where direct surface stream abstractions in the growth season are impossible due to the water body status, or when surface water streams are too distant. LIS development is thus related to, to certain extent, inter-dependent measures of the RBMP (DDU26 and DDU19). It also shows that merely implementing the measure DDU19 will not entirely define possible irrigation water use potential of reservoirs. This indicates the work of the government will need to resolve around strategic questions of water infrastructure use to help investors of LIS in irrigation development.

Groundwater

Groundwater availability shows the used groundwater quantities range within 1 – 41 %, and reach 30 % or less at 18 out of 21 groundwater bodies. Paradoxically more than 25 % of potential water rights are readily granted on 12 out of 21 groundwater bodies. Therefore the abstraction licence limits are reached administratively rather than hydrologically.

The expected fixed costs per borehole vary significantly with groundwater accessibility classes: high (€ 11 K, (100 mm, and capacity 5.5 l s^{-1}), medium (€ 15 – 30 K, (100 mm, and capacity 5.1 l s^{-1}), and low accessibility (€ 44.3 K, (100 mm, and capacity 1.1 l s^{-1}). The available groundwater could cover the irrigation water demand for 117,950 ha of all potentially irrigable land. The irrigable land share percentage is respectively $\geq 0 < 50$, $\geq 50 < 100$, or equals 100 % on 5, 4, and 12 groundwater bodies (Figure 2).

The distribution of potentially irrigable land is most dense in the areas of highest accessibility, which are also most vulnerable in terms of their chemical status under the RBMP. The most spread are medium accessibility areas, followed by low accessibility areas. These are more vulnerable to water abstractions as their water level decreases drastically thus major LIS development would not be appropriate at these areas.

Conclusions

Projections of future irrigation water use show the current water use for irrigation will increase. A national plan is to implement 4000 ha new LIS. However no spatial reference on where this development will happen is defined thus the projection poorly informs the DDU26 implementation of the RBMP set out to achieve good status of water under the WFD.

To overpass the sectoral gap and inform spatially weighted irrigation development that relates to water source use potential pertaining current protection aspirations under the RBMP, we document the development of the irrigation water use potential algorithm (IWUP). IWUP is a decision tree that helps choose best suitable irrigation water source of several available. The water sources use suitability is ranked on a scale from highly suitable for use to least suitable for use. Use priority of water sources for irrigation decreases accordingly: surface water stream, reservoir, and groundwater.

Two thirds of surface water streams show either negative irrigation use potential or limited irrigation use potential. A third of surface water streams show fairly good or very good irrigation water use potential. This indicates negative LIS development sites and LIS development hot-spots. Where surface water streams are unavailable the existing water reservoirs are the next suitable irrigation water source. The total estimated water storage potential 16.9 MM m^3 (6,770 ha) is sufficient for 44 % of all potentially irrigable land at the impact area of the reservoirs. Where no surface water is available groundwater could be used for irrigation. The available groundwater could cover the irrigation water demand for 117,950 ha of all potentially irrigable land. However, protected as drinking water and with extremely diverse accessibility its use for development of LIS has serious drawbacks.

Using IWUP enables sound decision making in terms of where LIS development should happen but at the same time informs the implementation of the DDU26. Although the IWUP was applied site specific the factors that define it could be adapted to any hydrological area regardless of administrative boundaries therefore has international relevance.

References

Barazzuoli P., Micheluccini M., Salleolini M., Salvadori L. (1986). Valutazione delle risorse idriche nella Toscana meridionale: Applicazione del metodo di Kennessey al bacino del torrente Farma e sua verifica con icalcoli di bilancio, Boll. Soc. Geol. Ital.

Cvejić R., Tratnik M., Zupanc V., Pintar M. (2010). Agricultural plants on irrigations systems in Slovenia for the period 2006-2009. In: Ačko D, Čeh B (eds) Proc New challenges in field crop production 2010, Rogaška Slatina, Slovenia, pp 320-326

Directive 2000/60/EC. The water framework directive. European Commission, 2000

Official Gazette No 67/2002, Republic of Slovenia. Water Act

Official Gazette No 63/2005, Republic of Slovenia. Rules on determining water bodies of groundwater

Official Gazette No 122/2008, Republic of Slovenia. Rules on evidence of actual agricultural and forestal land use

Official Gazette, No 14/2009 and 98/2010, Republic of Slovenia. Decree on surface water status

Official Gazette No 97/2009, Republic of Slovenia. Decree on criteria for determination and the mode of monitoring and reporting of ecologically acceptable flow

Official Gazette, No 97/2009, Republic of Slovenia. Rules on determination and classification for water bodies on surface water

RBMP, 2011. River basin management plan for the Danube and Adriatic Sea basin districts, Ministry for agriculture and environment of the Republic of Slovenia

acs79_07