Karst aquifers recharge and its relation with flood formation in the Vipava/Vipacco basin

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1. Introduction

In karst basins a strong mutual interaction between streamflow and groundwater is often observed and can affect flood formation and runoff propagation. Aiming at characterising the runoff regime of the transnational Vipava/Vipacco karst basin (650 km^2, Eastern Alps, SLO/I), which is a case study of the FP7 KULTURisk research project, the natural groundwater recharge was investigated. The Vipava/Vipacco river is a left tributary of the Soča/Isonzo river, and its main course is 50 km long. A large amount of data, provided by the Alto Adriatico Water Authority and by the Slovenian Environment Agency was collected, including time series from 7 stream gauges, 10 groundwater level measurement station and 9 rain gauges. Data covers a time period lasting since 1948 until 2011. Groundwater level data were available at a daily scale, and runoff and precipitation time–series are available both at daily and, for some stations, at hourly scale. An indirect approach, based on the stochastic univariate and multivariate correlation between groundwater levels, precipitation and hydrometric time series was adopted. It allowed to evaluate the characteristics of the groundwater recharge, due both to infiltration and to percolation from the stream channel, and its effect on the baseflow. As the hydrological response of a karst aquifer to an intense precipitation is strongly characterised by its initial conditions, a more detailed analysis was conducted for the most relevant flood events since 1998, in order to study the groundwater feedback to a severe water input in areas close to the stream channel. Considering flood events, it also allowed to neglect the evapotranspiration, and to estimate the basin infiltration. This section of the study is preliminary to model the basin in view of predicting flood events.

2. The Vipava/Vipacco watershed

The Vipava/Vipacco river is, in the left bank, the most important tributary of the Soča/Isonzo, which is a 140 km long river with a catchment area of 3400 km^2, flowing through western Slovenia (2250 km^2) and northeastern Italy (1150 km^2).

The Vipava river originates in the Slovenian territory, and develops a catchment area of about 20% of the whole Soča/Isonzo area. Due to the surrounding mountain karst areas, its effective area is unknown. The hydrographic area is about 653 km^2, and an external area of about 53 km^2 is usually considered to contribute to the basin, due to the presence of karst springs at the eastern boundaries of the catchment. The Vipava river flows mainly on limestone ground, with some layer of clays and sandstone.

The Vipava syncline is enclosed between the karst plateaus of Tarnova and Piro Northward, and the dolomite and limestone mountains belonging to Kras/Carso Triestino Southward. Subterranean drainage under these mountains is substantially unknown. Its groundwater bed could partially feed, in the left bank, the Doberdò, Pietrarossa and Sablici karst lakes. There is a certain probability that a part of the karst waters of the Tarnova Plateau flows under the Vipacco valley without any influence on the river.

Figure 1: Soča/Isonzo and Vipava/Vipacco Watershed

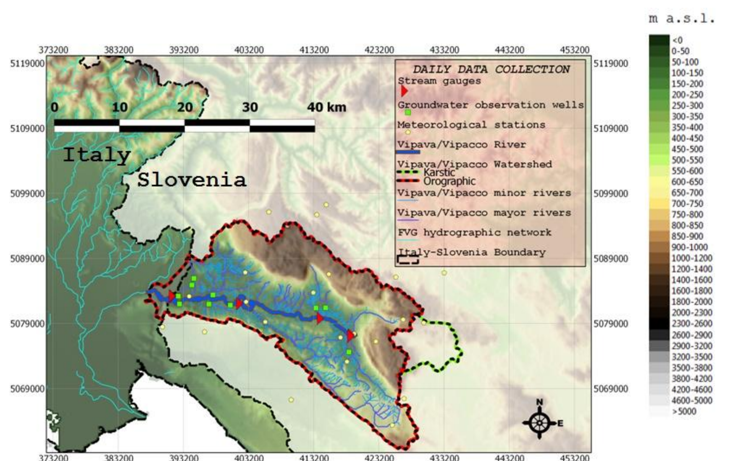

Figure 2: The Vipava/Vipacco Watershed (DEM)

The Vipava river rises from a karst spring group at the foot of the M. Nanos, than, moving from East to West, there are the Hubel springs (near Ajdovscina/Aidussina) and the Liak springs (near Gorizia), both on the right bank.

The Vipacco river flows in the Southern part of its own valley, touching and engraving (between Batuje/Battuglia and Dornberk/Montespino) the flyschoid hills, leaned on the Kras (Fig. 3). Near Dornberk the river creates thick meanders, receiving waters also from the Branica/Branizza creek. Downstream to the Liak, always on the right bank, the Vipava river receives waters from the Vrtojbica/Vertoibizza creek near the city of Miren/Merna (Fig. 4) [5]. In the last part of its path, the Vipava river interacts with the Doberdò karsts, with water losses for limestone absorption [1]; then it flows into the Isonzo river near the city of Savogna d'Isonzo.

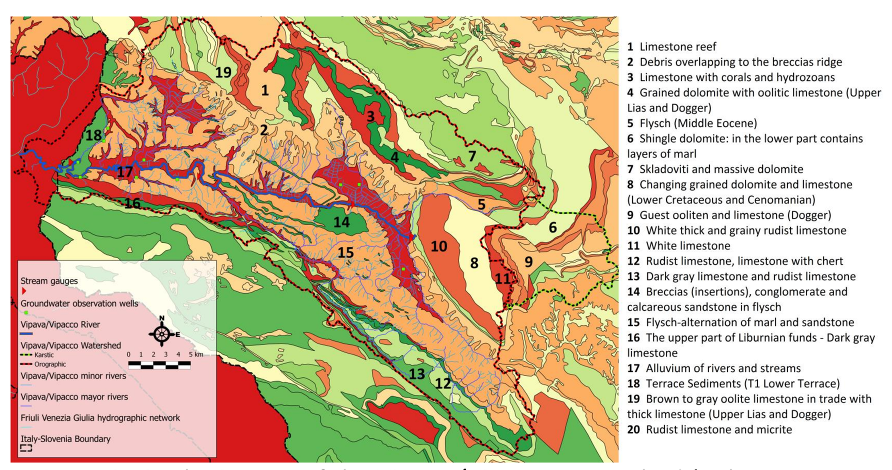

Figure 3: Geologic map of the Vipava/Vipacco watershed (only the main formations are specified)

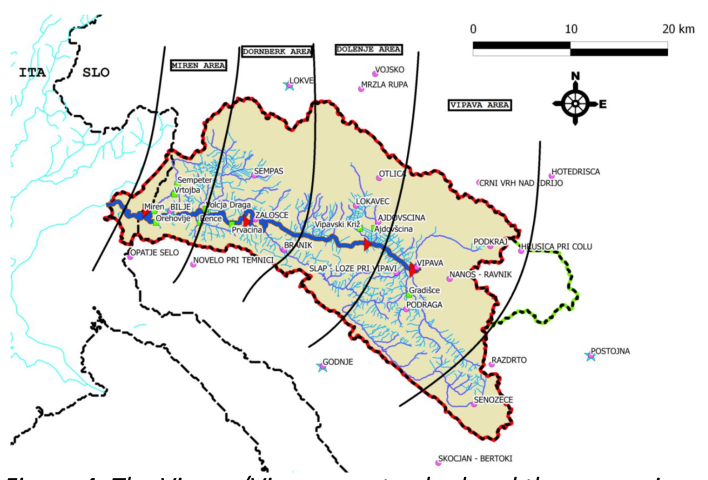

Figure 4: The Vipava/Vipacco watershed and the measuring stations

3. Correlation analysis

A stochastic univariate and multivariate approach, as suggested in [2,3,4] was adopted and conducted by 3 different steps, to analyze the relation between groundwater level (Z), streamflow (Q, Y) and precipitation (P) time-series from the measuring stations in Fig. 4.

1) The autocorrelation values for all the available station datasets (Q-P-Y-Z) and with a lag up to 10 days were evaluated. Results for groundwater levels and precipitation are shown in Fig. 5 and 6.

P-autocorrelation decreases quickly in the very first days, while the autocorrelation values for the groundwater datasets in the first 10 days are greater than 0.5. This behavior shows the slower reaction in time of the groundwater to a meteorological input. Similar results were obtained with the autocorrelation analysis for the discharge and the hydrometric data.

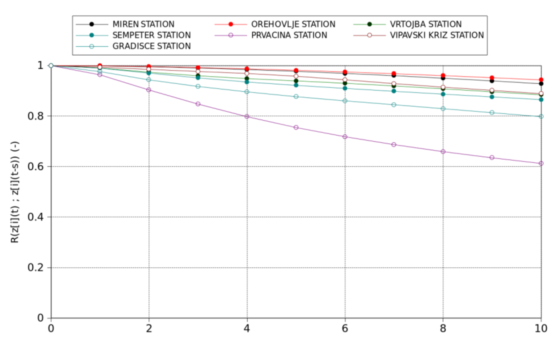

Figure 5: Autocorrelation of daily groundwater level measurements (lag: 0 to 7 days)

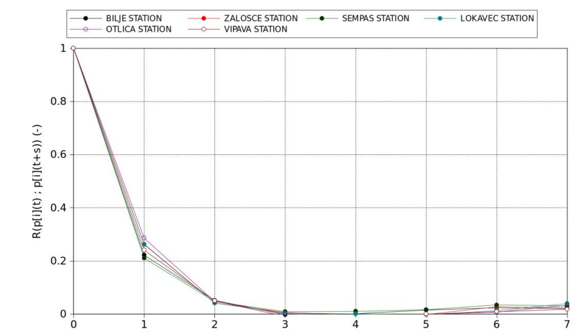

Figure 6: Autocorrelation of daily precipitation measurements (lag: 0 to 10 days)

2) The correlation between homogeneous variables was then estimated. The obtained values (with time lags between 0 and 7 days) shown in figure 7 and 8 are referred to the Bilje station (for P) and the Miren stream gauge (for Q). In both cases similar correlation trends between the stations are pointed out.

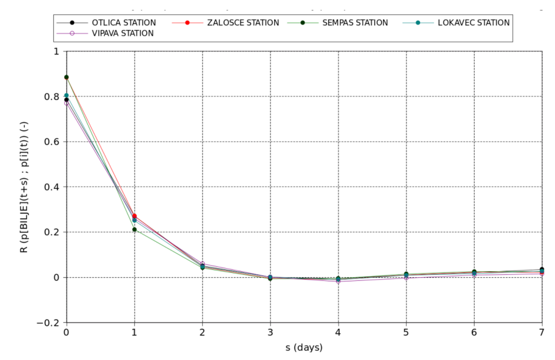

Figure 7: Correlation between daily precipitation at Bilje station and daily precipitation in the other precipitation stations

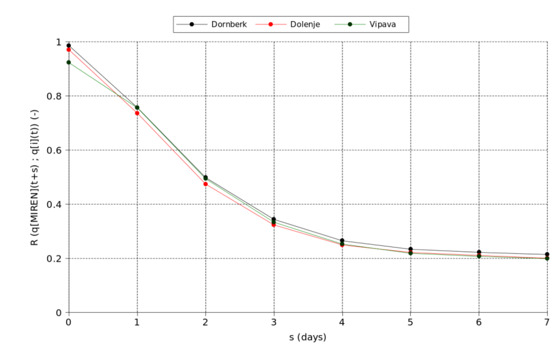

Figure 8: Correlation between daily discharge at Miren station and daily discharge in the other stations.

3) A cross-correlation analysis was conducted taking into account heterogeneous time-series from nearby stations (according to the definition of four regions surrounding the stream gauges, as shown in Fig. 4). The highest correlation (R_{max}) between precipitation and groundwater level matches with a 1 week lag in three regions (Dolenje, Dornberk, Vipava), showing a relatively fast aquifer recharge (Fig. 9). In Miren area, two different trends can be observed: both Sempeter and Vrtojba stations reach the R_{max} index by 1-2 weeks; the highest values of correlation for Orehovlje and Miren stations coincide with a lag of 3-4 weeks, and the correlation decay is slower (Fig. 10). These different reactions of nearby aquifers mark the existence of an underground karst system connected to the alluvial plain.

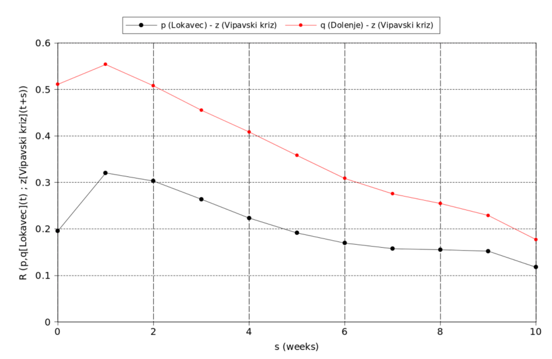

Figure 9: Cross-correlation between P(Lokavec), Q(Dolenje) and Z(Vipavski Kriz)

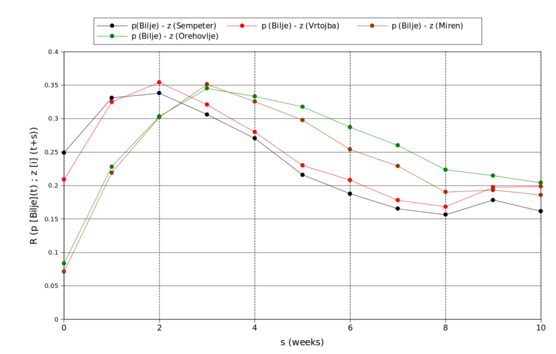

Figure 10: Cross-correlation between P(Bilje) and Z(Miren, Sempeter, Orehovlje, Sempter).

4. Flood events analysis

We collected and analyzed hourly discharge and precipitation datasets and daily groundwater level time-series for nine relevant Vipava's flood events in the 1998-2010 period. To a better evaluation of the groundwater conditions before and after each event, the considered time periods were extended to 55 days. To assess the existence of an external karst area feeding the Vipava's discharge we also considered a computational area as shown in Fig. 12.

The analysis was developed in the steps reported below:

1) Identification of the main flood events.

2) Detection of the sub-drainage basins for each stream gauge (Fig. 12).

3) Analysis of the hydrographs and the hyetographs for each event; interpolation of the daily groundwater level data.

4) Calculation of the runoff coefficients for each event and sub-basin outlet (see Table 1).

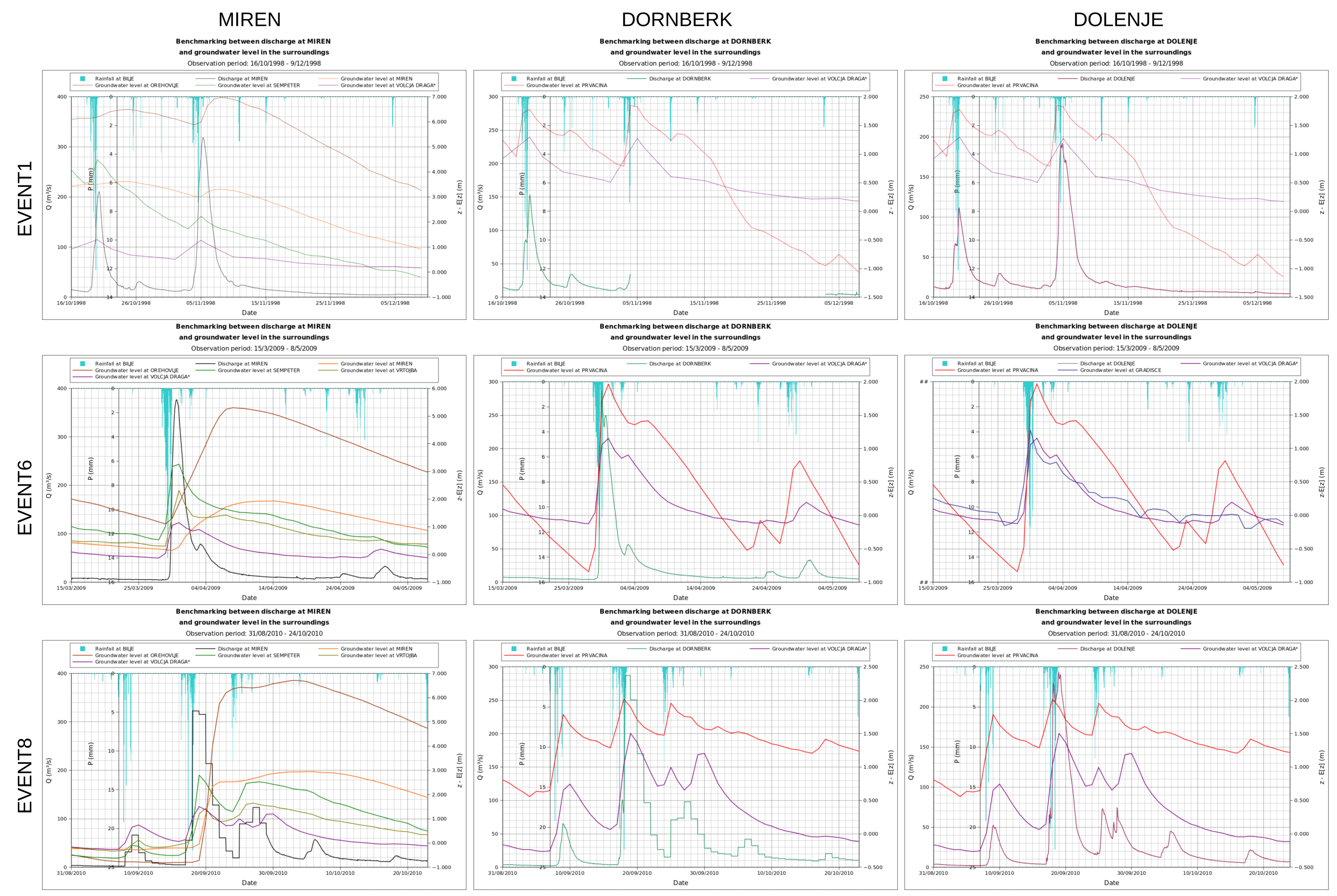

Figure 11: Hyetographs, hydrographs and groundwater levels for three flood events (extended time-windows)

		Hydr	Hydr+ Car	Hydr	Hydr+ Car	Hydr	Hydr+ Car
	Time-period	Miren	Miren	Dolenje	Dolenje	Dornberk	Dornberk
EVENT 1	26/10/1998 - 09/11/1998	0.590	-	0.710	-	-	-
EVENT 2	10/11/2000-24/11/2000	0.671	-	0.785	-	0.555	-
EVENT 3	16/01/2001 - 30/01/2001	0.625	0.563	0.748	0.607	-	-
EVENT 4	05/02/2007 - 19/02/2007	0.603	0.554	0.638	0.551	0.603	0.548
EVENT 5	01/12/2008-15/12/2008	0.660	0.651	0.758	0.743	N/A	N/A
EVENT 6	25/3/2009 - 08/04/2009	0.698	0.619	-	-	0.540	0.475
EVENT 7	17/12/2009 - 31/12/2010	0.572	0.499	-	-	0.489	0.418
EVENT 8	10/09/2010 - 24/09/2010	0.561	0.563	0.575	0.634	0.506	0.529
EVENT 9	01/12/2010 - 15/12/2010	0.596	0.653	0.813	0.687	0.655	0.588

Table 1: Calculated runoff coefficients

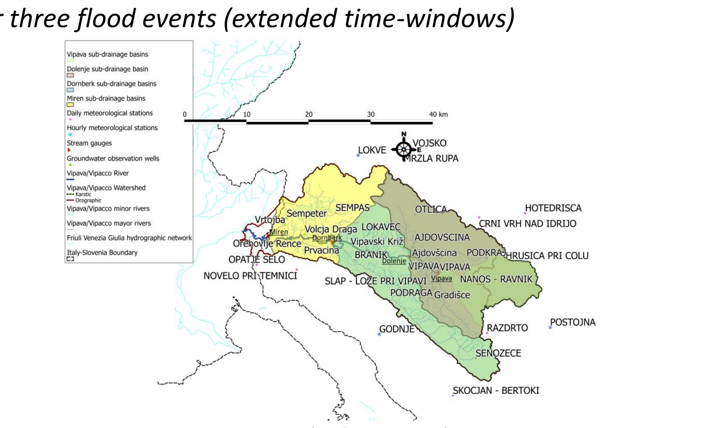

Figure 12: Sub-drainage basins

- Considering only the hydrographic sub-basins, the obtained runoff coefficients are relatively great even for severe but not extreme rainfall events; taking into account the external karst area, the runoff coefficients nearly always decrease (table 1). These results enforce the assumption of an external area feeding the Vipava discharge and the aquifer inside the basin. The many karst spring from the surrounding mountains could be partially responsible of the high values of the runoff coefficients, if only the hydrographic area is accounted for.

- In figure 11 three events over nine (Event 1, 6 and 8) are represented for the hydrographic station of Miren, Dornberk and Dolenje. Only two groundwater stations (Miren and Orehovlje) were observed with a slow recession of the groundwater level after a strong precipitation/discharge input. The aquifer recharge shown by the other piezometric stations reveals, instead, fast and strong rising/decreasing groundwater levels.

5. Conclusions

Data highlighted evidences of kars phenomena in the Vipava watershed:

1) Many springs from the karst plateau surrounding the catchment contribute to the river discharge. An external karst area feeds the Vipava watershed by means of springs at the foot of M. Nanos;

2) Groundwater oscillations have sensitively different patterns in different locations. Some piezometric wells show very quick response to precipitation.

Both correlation and flood formation analysis indicated the possibility of karst areas surrounding the cities of Dornberk and Miren. Confirming the direct surveys near the city of Miren/Merna, where the Vipacco river shows water losses due to an absorption through the karst limestone.

Acknowledgments and References

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[1] Albrecht P., Il fiume Isonzo – Descrizione fisica del Bacino dell'Isonzo e dei suoi affluenti, Normale (vol. 11, fasc. 24), 1988
[2] Box G.E.P., Jenkins G. M., Time series analysis: forecasting and control, Holden-Day, 1976
[3] Ford D., Williams P., Karst Hydrogeology and geomorphology, Wiley, 2007
[4] Kottegoda N.T., Stochastic water resources technology, The Macmillan Press LTD, 1980
[5] KULTURisk Project, Deliverable 2.2 – Baseline for the application of the risk-based methodology, 2011.

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