Reading a River's Deep Secrets

Water reaches a river in the form of surface runoff (precipitation that has not seeped into the ground) or underground outflow (groundwater). Both of these factors affect the erosion and river deposition processes that shape the river valley. Understanding them is crucial for effective river management.

Assoc. Prof. Tomasz Falkowski is a geologist from the Warsaw University of Life Sciences (SGGW), Faculty of Civil and Environmental Engineering. His work includes more than 70 peer-reviewed publications dealing with the geological composition of river valleys in terms of river engineering requirements, as well as the usefulness of morphogenetic analysis in documenting geological-engineering and hydrogeological conditions.

tomasz_falkowski@sggw.pl

Dr. Tomasz Falkowski,

Warsaw University of Life Sciences (SGGW)

Dr. Ewa Falkowska,

University of Warsaw

The erosion and transport of bedload do not occur in the same way throughout a given river valley, which instead can usually be seen to consist of several distinctly different sections. This segmentation is not only due to the location of the various sources and estuaries (which may be classified as juvenile, mature, or aged, corresponding to the upper, middle, and lower course of the river). One reason for such diversity may be the geological structure of the area cut through by the river: the valley develops differently when it splits soft stone than when it runs through hard rock. These differences are reflected in declines of the bottom of the valley, as well as changes in its width. The tectonic activity of the area may also be significant.

Another, more immediate factor driving the evolution of the river environment is the differences between extreme flows, in other words high and low river states. An example of this can be found in the development of the Middle Vistula River valley in the late Pleistocene and Holocene.

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River evolutions

The end of the Pleistocene made an impact on the Vistula valley in the form of intense filling of the valley bottom, left behind by a braided, heavily overloaded river. This process occurred in the conditions of absence of a dense forest cover and the presence of permafrost – factors which limited the infiltration of water and therefore favored surface runoff. Gradual climate warming led to increased rainwater infiltration and so raised the significance of underground outflow. As extreme flow variations decreased in intensity, the Vistula gradually formed a winding riverbed. At first these riverbed curves were rather large in radius. The smallest meanders were created in the period of the Holocene Climatic Optimum, which is called the Atlantic period, (6,000-8,000 years ago). Typical deposits of this calmly flowing meandering Vistula are clayey flood sediments (silts), in the Middle Vistula valley reaching up to 7m in thickness.

About 300-400 years ago the hydrological regime of rivers in the Polish Lowlands began to change. The cause was the growing impact of human activity, such as the cutting of forests for cultivation. This resulted in increased surface runoff and the return of major variations in the intensity of extreme flows.

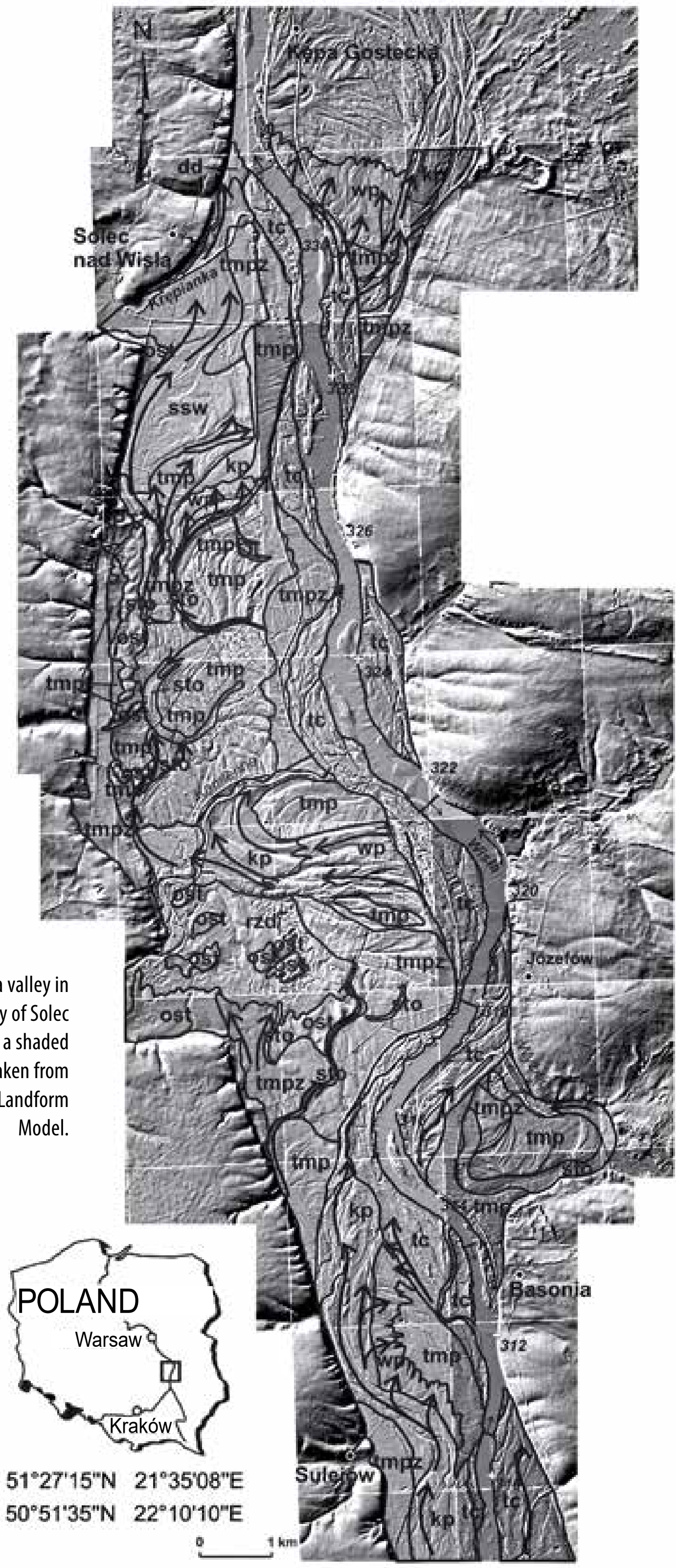
This resulted in the river reverting to braided, overloaded channels (returning to its "wilder" state) and transforming the bottom of the valley. Increasingly violent river flows transformed the individual sections of the Vistula valley floodplain to varying degrees, largely depending on the local geological structure. The Vistula valley is relatively young, its

Dr. Ewa Falkowska is a geologist from the University of Warsaw, Faculty of Geology, Independent Department for the Protection of the Environment and Natural Resources. She studies how the origins of landforms in the Polish Lowlands are related to the physico-chemical properties of sediments that compose them. These studies are used in analyzing risks to the geological environment due to the location of real estate development and economic activities.

ewa.falkowska@uw.edu.pl

Heavy metals in river waters

Heavy metals are present in river waters in dissolved form, in the form of aggregates precipitated from solutions, or as river bed load made of mineral or organic components. The biggest load of heavy metals is transported in rivers along with suspended sediments. Approximately 90–99% of this load relates to the transport of fraction particles <63 µm.



The Vistula valley in the vicinity of Solec nad Wisłą – a shaded image taken from the Digital Landform Model.

Symbols representing different types of landform:
tmpz, tmp, kp, ssw, rzd, sto, wp, tc, wp, dd, ost

Direction of flow of flood waters

A "step" formed in the alluvial basement

formation may have started after the disappearance of the last Scandinavian ice sheet. In the area of Central Poland, this happened about 230,000 years ago. This is the main reason why the erosional base of the valley is not fully developed. In areas where the valley substratum is made of deposits with a higher resistance to river erosion, such as moraine (glacial) clays or silts, they form morphological protrusions (beneath the channel alluvia layer). Such elements stabilize the deep erosion of rivers. Channel sections with the basement protrusion are also prone to ice jam formation.

An example of this is the so-called "Żoliborz threshold" in Warsaw, where in 2015, during a historically unusual period of low water in the Vistula riverbed, one could observe boulders lying on the surface of the Neogene clay layer. Such formations in the riverbeds of the Polish Lowlands are not uncommon, and are sometimes known locally as "reefs." In the past, these areas, due to the stability of the river bottom, were used as fords, and they were likely a factor determining the location of most of the cities founded on the banks of the Central Vistula. Most often, however, the rocks on the older substrate are covered over with a layer of loose sediments from the riverbed (in this case, sand with a small amount of gravel). When major flood waves occur, in addition to a rise in the water level, they also further lower the bottom surface of the riverbed by lifting loose sediment. This may expose an underlying surface built of resistant rocks, whose shape then affects the configuration of currents in the flood water, possibly directing it to the same floodplain zone during each rising stage. In some areas, these repeated river swells have partially or completely removed the clayey silts left over from the Holocene Climatic Optimum period. These flows are also responsible for flood erosion troughs of various dimensions – examples include the Czerniakowskie and Kamionkowskie Lakes in Warsaw. In some cases, such erosion troughs became filled up with modern flood sediment, more silty and sandy. The identification of areas where flood flows persistently concentrate is essential for the assessment of the stability of river-regulation structures, and for flood protection efforts.

Analysis of the river levee failures that occurred in the Vistula valley in recent years (1997, 2010, 2012) shows that they were not in fact caused by water flowing over the crest. Most often, levee failure can instead be attributed to filtration deformation at the base of the embankments, with the soil structure becoming disrupted by groundwater flowing at high velocity (the concentrated flow washes out loose, sandy sediment). Old flood erosion troughs refilled with loose riverbank sediment are predisposed to this type of deformation. Their presence in a given area is related to the broader geological structure of the river channel. Such levee

Riverbed varieties

The **hydrological regime** of a river, understood as the flow of water and sediment transport through the hydrological year, is primarily reflected in the shape of the riverbed. Generally we distinguish three main types of rivers, each with is own distinctive pattern: **meandering rivers**, having a tight, narrow, deep and winding riverbed; **braided rivers** consisting of a wide, shallow, multi-current riverbed with numerous islands and sandbanks; and **straight rivers** – having a straight riverbed, whose shape is mostly structural (their shape and course is based on boundaries of outcrops resistant to rock erosion). In addition to these, literature also mentions the multichannel **anastomosing** and **wandering rivers**.

sections, which are particularly at risk of failure, can therefore be identified by analyzing the landform of the floodplain.

Alluvial basement culminations are a common phenomenon in the river valleys of the Polish Lowlands, due to the aforementioned immaturity of the landscape. This defining feature of fluvial environments in post-glacial areas, such as the Polish Lowlands, has broad practical implications crucial for the economic development of riverbank zones and indeed the whole area of such river valley floodplains.

A metallic jigsaw puzzle

River processes also affect the distribution of pollutants carried by the river in alluvial sediments, which constitute another human footprint on this environment. In assessing the scale of human impact on the catchment or river valley areas, heavy metals play a significant role. Their presence indicates environmental degradation. The quantity of heavy metals transported depends on their physicochemical properties, as well as on the dynamics and chemical properties of the water environment.

The distribution of heavy metals in river sediments largely depends on the type of rocks that comprise those sediments: the amount of clay minerals and their mineral composition, the amount of organic matter, carbonates, iron oxides, hydroxides, etc. In addition to the chemical properties of the environment, the spatial distribution of heavy metals in sediments that compose the floodplain is also affected by processes that determine the transport and deposition of debris matter (small particle sediments transported in suspension). They depend on the hydrological regime of the river and the geomorphological conditions of flow and deposition. The lowest concentrations of heavy metals occur in zones with a stronger flow along the floodplain surface. Forecasting plays a crucial role in valley management, such as predicting in which areas there is a risk of previously deposited sediments that contain a significant load of heavy metals being washed away. Such analysis may be effectively carried out by identifying the morphology and the origins of the valley bottom.

In the central Vistula valley the highest concentrations of heavy metals occur within the sediments that compose alluvial cones formed by flood waters, and within oxbow lakes. The lowest content of heavy metals can be found in the sediments that fill the flood flow channels in floodplain areas.

A challenge for the researcher

The varying geological structure of river valley areas (especially the morphology and lithology of the riverbed bottom) is a crucial factor to consider when choosing water intake sites. The bottom infiltration intakes utilized in Warsaw ("Gruba Kaska","Praga Bis", and the left bank intakes PU-1, PU-2, PU-3) require adequate thickness of the layer of the sandy alluvial deposits, from which water is taken away through a system of radially arranged drains. The thickness of the sandy alluvial deposits on the section of the Vistula riverbed running through Warsaw is variable, ranging from zero to approx. 20 m. For example, near the central railway bridge or along the Metro tunnel running under the river, the riverbed basically lacks any alluvial layer. The Metro line tunnel runs through a series of low permeable Neogene silts that form several alluvial basement culminations in the Warsaw section of the Vistula riverbed.

Despite our growing knowledge of the mechanisms of transport, erosion and deposition, river valleys still represent a difficult challenge for researchers and practitioners because of the variety of factors that shape the flow of river waters and also the diverse initial conditions underlying valley formation. Each section of a river valley has its own unique characteristics, so proper management of various parts of the valley requires an individual approach, both at the research planning stage, and while implementing a particular project to develop a given segment. Geological research is particularly important in diagnosing conditions for the economic development of river valley sections. Detailed knowledge of the geological structure of the valley bottom of the Vistula River is essential for the utilization of its resources, and has a direct impact on the safety and quality of life for citizens.

Tomasz Falkowski, Ewa Falkowska

GLOSSARY

Alluvia
– sediment deposited by flowing water.

Aggradation
– the deposition of material transported by the river onto the valley bottom.

Degradation
– river downcutting, lowering the valley bottom.

Bed load
– all solid and dissolved materials transported by a river.

Erosion troughs
– formed due to rapid erosion by the flow of flood waters.

Flood water cones
– formed at the mouth of erosion troughs through the deposition of material taken from the floodplain.

Further reading:

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