Clearing the *Beautiful Blue Danube*

BY TOSA NINKOV, PHD, SE

In 1999, in response to the unsettling conflict between the Serbs and the ethnic Albanians of Kosovo over control of the southern province, NATO aircraft destroyed three bridges across the Danube River at the city of Novi Sad in Serbia. Remaining submerged debris and unexploded ordnances (UXOs) posed such serious hazards to river traffic that only the smallest ships could squeeze through a temporary channel for nearly four years. In 2002, PMC Engineering of Belgrade, in cooperation with the Faculty of Technical Sciences from Novi Sad and the Geophysical Institute from Belgrade integrated Real-Time Kinematic (RTK) Global Positioning System (GPS) technology with underwater sonar and proton magnetometer devices to map the riverbed and locate the submerged UXOs. Six live shells were removed during cleanup, and river traffic is now gradually returning to its pre-war levels.

GPS and geomagnetic surveying makes the Danube River safe again.

A River Stricken

Rising in the hills of the Black Forest in Germany, the Danube River flows eastward 2,850 km to the Black Sea. The second longest river in Europe (after the Volga), the Danube has been an important transportation route for nearly 2,000 years. In the 200s, it formed the northern border of the Roman Empire. Today, it flows through 12 countries* and links numerous cities including Vienna, Budapest, Bratislava and Belgrade. Canal connections to the Rhine, Odra and Main Rivers provide a waterway that links the North Sea and the Black Sea through the heart of Europe, making the Danube a major artery for commercial transportation. But in 1999, the artery was blocked following the NATO destruction.

About 75 km northwest of Belgrade in the Vojvodina province, the river port city of Novi Sad was filled with some 800 commercial ships per month before the onset of NATO actions in Kosovo. But in 1999, NATO forces targeted and destroyed all three of Novi Sad's bridges: the Zezlj, the Petrovaradin and the Sloboda. The 500- to 800-meter width of the river was littered with concrete and twisted metal, and it was believed that there were up to 10 unexploded ordnances hidden in the debris or embedded in the sediment. Commercial shipping was essentially eliminated.

For four years afterward, the river was closed to traffic, the damaged bridge spans were removed, a pontoon crossing was set in place, and a 70-meter-wide channel was cleared through the river. These actions enabled some river traffic to resume, but it was limited to small ships that could navigate through the narrow, temporary channel. Many shipping organizations switched to trucks as their transportation means to bypass the stricken river. The estimated economic loss was one million euros per day, with major ports in Romania and Bulgaria bearing the brunt of the shortfall.

Planning the Rebirth of the River

In 2002, with the backing of 26 million euros provided by the European Union, the Danube Commission, an international organization overseeing operations on the river, awarded contracts for a major cleanup project to clear the river of debris and UXOs, and enable traffic to return to pre-war levels.

The project was awarded to a team headed by PMC Engineering, with assistance from the Faculty of Technical Sciences from Novi Sad, the Geomagnetic Institute of Serbia, and a military ordnance disposal unit to map the river bottom, and locate and remove suspected UXOs. The team proposed to conduct a survey of the river bottom and its banks using a combination of geophysical technology, including echo-sounding sonar, geomagnetic measurement and metal detection. These geophysical methods would be integrated directly with RTK GPS data collection to create a digital terrain model (DTM) of the riverbed.

Every phase of the project would rely on the accuracy of the three-dimensional riverbed map; the quality of the resulting hydrographic DTM was essential to the success of the project. The DTM would be used to plan magnetometer trajectories along the axis of the river to avoid potentially dangerous obstacles protruding from the river bottom. Boats bearing the magnetometer devices would then use RTK GPS to precisely navigate along these routes to determine the locations of suspected UXOs or other dangerous materials. When suspect objects were located, their precise position would be marked on the DTM maps to enable military divers to locate and examine them in the Danube's murky waters.

Making the Initial Survey

The survey area was defined to extend along the river for 5,200 meters and include the full 500- to 800-meter width of the river plus 100 meters of the riverbank on each shore. This swath totaled 1.2 million square meters and contained all three bridges, scattered debris and potential UXO locations.

The riverbed map and the DTM were created using a Trimble (Sunnyvale, Calif.) 5700 RTK GPS base station, which was placed on known control points in a project control network covering the entire area. A 5700 RTK GPS rover system was mounted in the survey boat. A Trimble TRIMTALK 450S UHF radio modem provided RTK corrections between the base station and rover units; the RTK corrections provided centimeter-level accuracy for the location of the acquired points. The radio modem provided a wireless data link to the rover unit at distances up to 10 km from the base station.

The nine-meter-long survey boat was equipped with a vertical acoustic probe, which extended into the water. An Atlas (Sydney, Australia) Deso 300 single channel echosounder sonar unit was attached to the end of the probe underwater. The sonar device determined the water's

Dr. S. Mihailovic (geophysical expert) and Dj.Ninkov on station with a Trimble Pathfinder and TRIMTALK 450S UHF radio modem as base station for navigation during geophysical investigations.

**The Danube River passes through Germany, Austria, Slovakia, Hungary, Slovenia, Croatia, Serbia, Bosnia and Herzegovina, Bulgaria, Romania and the Ukraine.*

Dipl.Inz. of Surveying, C. Krulj, uses a Trimble 5700 GPS system for RTK measurements on the Danube River project.

Dj.Ninkov and C. Krulj use the Trimble 5700 GPS Base Station and TRIMTALK 450S UHF radio modem for RTK measurements.

Professor Ninkov stands before a damaged bridge during hydrographic measurements.

depth by emitting sound waves that reflected off the river bottom. The rover GPS antenna was mounted on the end of the acoustic probe above-water and integrated with the sonar, so that each water depth reading acquired by the sounding device was tagged with a highly accurate, georeferenced *x*, *y*, and *z* coordinate.

Depth data was recorded every two meters along the boat's path in traverses perpendicular to the axis of the river; the traverses were 10 meters apart. Trimble HYDROpro navigation software, running on a laptop computer and interfaced with the sonar and GPS, provided navigation displays and synchronized the data collection between the GPS and sonar. The software also integrated the collected sonar and GPS data and derived bottom-point coordinates. The data processing also corrected sonar data that was skewed by waves and eliminated low-quality data.

The coordinate points were transferred to an Excel spreadsheet, which were then translated into topographic values for the riverbed. This topographic data was then transferred to ESRI (Redlands, Calif.) ArcGIS software where it was extrapolated to generate the DTM of the riverbed.

Locating the Dangers

The goal of the project's second phase was to locate underwater features that might be UXOs or other potentially dangerous bridge debris, such as metal objects, blocks of reinforced concrete, metal pipes and wire ropes. This was done using a GSM-10 proton magnetometer provided by the Geomagnetic Institute of Serbia to measure perturbations in the geomagnetic field along the river bottom.

The team used the DTM as a base map to plan 50 to 80 georeferenced trajectories parallel to the river axis; the trajectories were each separated by 10 meters. These were the guide routes for the boat towing the magnetometer.

To offset the continuous, natural variations in the earth's magnetic field, geomagnetic surveying was performed similarly to differential GPS surveying using a base station and a rover instrument. The local base station was a magnetometer on the shore located away from any metal objects. Its recordings, coupled with secondary measurements made by the Geomagnetic Observatory in Belgrade, provided the baseline geomagnetic readings.

The rover proton magnetometer was towed down the river behind a rubber dinghy along the previously mapped trajectories parallel to the river's axis. When the rover passed over a metallic feature, it registered an increased geomagnetic intensity measured in nanoTeslas (otherwise known as the "F" value). The magnetometer sampled the geomagnetic field intensity every five seconds (or roughly two meters) as the dinghy floated downriver.

In addition to the 5700 GPS receiver on the survey boat, the dinghy crew used a handheld Trimble GeoExplorer GPS receiver, which provided navigation and

The Danube River survey team shows an unexploded ordnance removed from the Danube River.

geo-referencing functions for the operation. The georeferenced trajectories were uploaded into the GeoExplorer to provide navigation information. The GeoExplorer and the magnetometer were integrated to affix GPS locations to each measurement. A Trimble GPS Pathfinder Pro XRS receiver acted as a base station on the shore to provide increased GPS position accuracy.

A field crew, using handheld ground penetrating radar devices from Malå Geoscience (Malå, Sweden, and Charleston, S.C.), also made a systematic search along the shoreline during this phase for UXOs that might be hidden in the vegetation or embedded in the soil.

At the office, a team from the Faculty of Technical Sciences used Trimble GPS Pathfinder Office software to correct the GPS data accuracy to within a few decimeters and to geo-reference the geomagnetic intensity data from the river traverses. ArcGIS software was then used to compare the data with the two sources of baseline geomagnetic variations and identify incidents of high F values in the river data that did not coincide with natural magnetic variations.

The numerous geomagnetic anomalies were displayed in 2D and 3D by the GIS software. By using the images to determine the probable features, the team was able to sort the objects into three principal groups: large geometric objects were likely foundation pieces of the bridges; irregular shapes were assumed to be structural components; and smaller cylindrical or spherical items were labeled as possible UXOs.

It was important for the dive team's safety to differentiate between features lying on the riverbed and those that were buried beneath the silt. This was accomplished by overlaying the 3D geomagnetic intensity grid over the river bottom DTM in the GIS.

Because the UXOs were almost entirely metal, PMC Engineering personnel performed another survey of the river as an additional filter. An MD-2 Ferex metal detector (Foerster Instruments Incorporated, Pittsburgh, Pa.) was towed over the high-intensity geomagnetic zones. The high-F targets that also gave strong metal detector responses were labeled "primary critical zones" requiring immediate attention. Anomalous sites with low metal returns were categorized as "secondary critical zones" worthy of attention after the divers had inspected the primary zones. A total of 47 primary and 60 secondary critical zones were pinpointed for visits by the military dive team.

Eliminating the Dangers

In the third phase, the dive teams used the 3D maps and GPS to navigate their boats to each dive zone. The precise locations were critical for safety because the water conditions were challenging. The fast current was very turbulent due to the bridge wreckage. The water was also cold and extremely muddy, limiting the time the divers could spend in the water and restricting average visibility at the riverbed to only 20 to 40 cm.

Guided by the GIS maps, the divers were able to inspect every target without injury. Six UXOs were discovered, all from the primary critical zones. These were removed by the disposal experts. Interestingly, only three of the UXOs came from the 1999 NATO raids; the others were remains from World War II.

With the UXOs removed, demolition crews could recover bridge debris much more rapidly. Normal shipping traffic on the river will resume when reconstruction of the Sloboda Bridge is completed and the temporary pontoon bridge is removed.

In mid-1999, Serbian troops withdrew from Kosovo, NATO air campaigns halted and an international peacekeeping agreement was authorized as a resolution to the conflict in Kosovo. Thanks to the efforts of PMC Engineering, the Faculty of Technical Sciences and the Geophysical Institute from Belgrade, the Danube River is again safe as a transportation course for the 12 countries it serves, and the future completion of the bridges in Novi Sad is in immediate sight.

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