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Final Report

Scour Monitoring of Indiana Streams

FHWA/IN/JTRP-2002/8

by

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Scour Monitoring of Indiana Streams

Introduction

INDOT is considering the deployment of fixed scour-monitoring instrumentation in the field as part of a systematic response to the problem of scour around bridge piers and the associated FHWA mandates. A previous study had undertaken to investigate two types of scour monitors, one based on a sliding magnetic collar, the other based on a sonar. During two flow events however, the monitors suffered significant damage. This led to a re-design and modifications of how the sonar-based device was mounted to the pier. The latest configuration of the sonar mounting had been tested in the field for only a year before the end of the previous project, and this was insufficient to yield any definitive recommendations regarding its wider deployment. Similarly, a re-design of the means by which cables from the sliding magnetic collar were routed to the bridge-deck instrumentation box had been suggested but not investigated in depth. The present project therefore aimed at a more extensive testing of the sonar monitor, and an examination of the feasibility of a more robust cable routing for the sliding-collar monitor.

Findings

An on-site investigation (at the SR25 crossing of Wildcat Creek), involving wading out to the pier in a wet suit, indicated that a large and deep scour hole had developed in the vicinity of the magnetic-collar device. An attempt to locate the device on the stream-bed proved unsuccessful, and it was surmised that the device was no longer in its installed position. Because of the size and depth of the scour hole, the proposed re-design of the cable routing would not be, if not physically impossible, certainly not economically feasible.

The testing of the sonar was more successful. Over a period exceeding 24 months, the sonar device at the US52 crossing of the Wabash River has operated continuously without any difficulties due to damage by floating debris. It has survived several large flow events, though an event of magnitude equal to or larger than that that had previously caused damage did not occur during the testing period. A study of the sonar reading and the corresponding hydrological parameter (river stage) indicated a definite correlation. This is interpreted as evidence that the sonar monitor is reliably providing information regarding the bed level, which is known to vary with stage.

The merits and deficiencies of the different types of scour monitors, including a portable or mobile sonar monitor, are discussed, and recommendations as to type of situations under which each scour monitor might be appropriate are made.

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16. Abstract

The project examines the survivability and reliability of fixed-in-place continuous scour monitors for possible use in Indiana streams. The report considers primarily the experience with a sonar device at the US52 crossing of the Wabash River. Although very large flow events did not occur over the project period, the device has survived a number of smaller events, and has operated continuously without failure due to physical damage. Further, the data obtained, after appropriate processing, were examined for their credibility in terms of their correlation with a hydrologic parameter, the stage. A reasonably strong correlation was found, suggesting that the recorded data from the sonar monitor are a reliable indicator of scour (and fill). Recommendations are given regarding the applicability of the various different types of scour monitoring devices.

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Introduction

The present project is an extension of a previous JTRP project in which two sets of two different types of continuous scour-monitoring devices were installed at two sites (Cooper et al., 2000). These devices are being considered as potentially useful tools in a broad management strategy for responding to and dealing with the scour around bridge piers. During the course of the original project, it was observed that both devices, one based on a magnetic collar installed on and free to slide down a steel rod driven into the streambed, and the other based on a sonar device mounted on the bridge pier, were particularly susceptible to damage and/or being rendered inoperable by floating debris.

At one site, the US52 crossing of the Wabash River, the conduit containing the electrical and data cables from the sonar device to the on-deck equipment box was completely severed within a month of its initial installation. After its repair and its re-installation with modifications to make it more robust, the unit operated without major problems for approximately 15 months, when the sonar transceiver was apparently detached from its pier mount and carried away during a large flow event. A new transceiver was again installed, with further armoring modifications (details of the modifications are given in the report by Cooper et al. 2000), but had only been in operation for less than a year before the end of the project.

Because of the short length of time in which the sonar device was in operation in the previous project, during which few if any large flow event occurred, a definitive conclusion regarding the survivability of the device could not be reached. The current work was mainly intended to provide a longer-term assessment of the survivability of the sonar device at the Wabash River site.

At the other site (SR25 crossing of Wildcat Creek), minor damage had also been incurred by both devices over the course of the previous project. It should be pointed out that the installation at the Wildcat Creek, which was completed at a later date than that at the Wabash River site, benefited from the experience at the latter site, and this may have contributed to the less serious damage observed at the Wildcat Creek site. Because of chronic problems with debris accumulation at the pier where the devices were installed, the sonar device, though largely intact physically, did not yield any useful data. As such, further effort to repair the sonar device was considered not worthwhile.

In contrast, the data obtained via the magnetic-collar device were quite interesting in indicating substantial scour (almost 3 ft in total over an approximately two-year period). Towards the end of the previous project, the conduit from the magnetic-collar device along which the electrical and data cables were routed was ruptured. At the beginning of the current project, it was decided that the past performance of the magnetic-collar device warranted an attempt at a repair or re-design of the manner by means of which the cables were routed. An initial site inspection, including wading in a wet suit to the pier in question, confirmed the presence of a large scour hole, but attempts to locate the steel rod driven into the streambed proved unsuccessful. The proposed re-designed cable conduit, based on a continuous rigid armored section from the pier to the top of the steel rod,

required that the top of the steel rod be relatively close to the pier in order for installation to be feasible. Due to the larger than expected scour hole, it was decided that a repair/-reinstallation of the magnetic-collar device at the Wildcat Creek site would after all not be attempted.

The remainder of this report will therefore deal solely with the performance of the sonar device installation at the Wabash River site. The flow events occurring over the current project period will be discussed. A test of the device undertaken in 2001 will be described. A secondary aim of the current project was the extension of the time series of scour-monitoring data so as to obtain a larger sample of data for a study of the relationship between local pier scour and hydrologic parameters.

The flow events

Hourly flow data used to identify hydrological events were based on data from a nearby USGS gaging station (station no. 03335500) located less than 1 mile downstream of the Wabash River site. Flood stage at the Wabash River station is declared at a stage of 11 ft, corresponding to a discharge of 17,300 cfs. Fig. 1 shows a stage and discharge data for the previous project period (6/1/97-2/1/00) for the Wabash River. The two instances when the device failed due to damage have been indicated, and it is clear that both incidents coincided with flood events. The first failure occurred at a flood stage of 18.6 ft and 41,712 cfs, while the second failure occurred a flood stage of 21.8 ft and a discharge of 61,097 cfs, by far the largest event so far recorded (including the current project period). In spite of this, an examination of the maximum annual flow series for this station (based on 97 years of data from 1901 to 2000) indicates that a discharge of 61,097 cfs corresponds to an average return period of ≈ 3.5 years.

For comparison, the stage and discharge time series for the current project period (6/1/2000-2/1/2002) are shown in Fig. 2. Several flood events may be identified, the largest of which (a stage of 18.4 ft and discharge of 40657 cfs) was comparable to the event associated with the first failure. Since its last repair, re-design, and re-installation in November 1999, i.e., a period of over 25 months, the sonar device has operated without failure due to damage. Because of the absence of very large events during the project period, a definitive statement concerning the survivability of the device cannot yet be justified. Nevertheless, it is believed that, with the modifications made, the device would survive an event of magnitude at least equal and more likely greater than the event that caused the last failure. That the device has so far operated continuously without damage does give some positive indication that the sonar device can be practically and profitably deployed in the field under appropriate conditions.

The performance of the sonar scour monitor

An overall overview of the data obtained with the sonar device is given in Fig. 3, where the sonar reading is plotted with the stage. As was found in the previous project period, a large scatter can be seen in the sonar data, with fluctuations of 5 ft common in the readings. The sonar operates properly only when it is submerged, and as such the sonar readings at low stage when it could not be submerged should be discarded. This has been done in Fig. 4, where only those sonar readings were retained which corresponded to a

stage greater than 7.25 ft. A significant reduction in the scatter can be seen, except at isolated instants during the flow events of 6/14/00, 1/31/01, 10/12/01, when erratic spikes in sonar readings are evident. It should also be recalled that the sonar reading *increases* when the streambed *recedes,* presumably as a result of local scour.

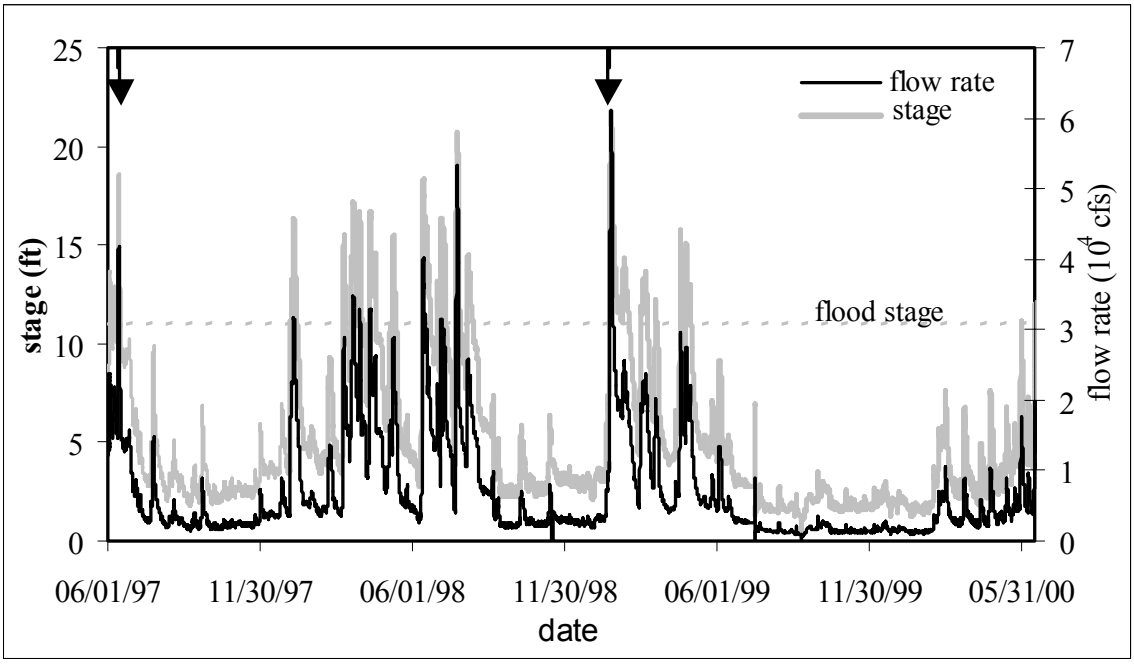

Fig. 1: Time series of stage and discharge for the Wabash River at Lafayette over the previous project period (6/1/97-5/31/00); the arrows indicate the date when the sonar device failed due to damage during a flood event

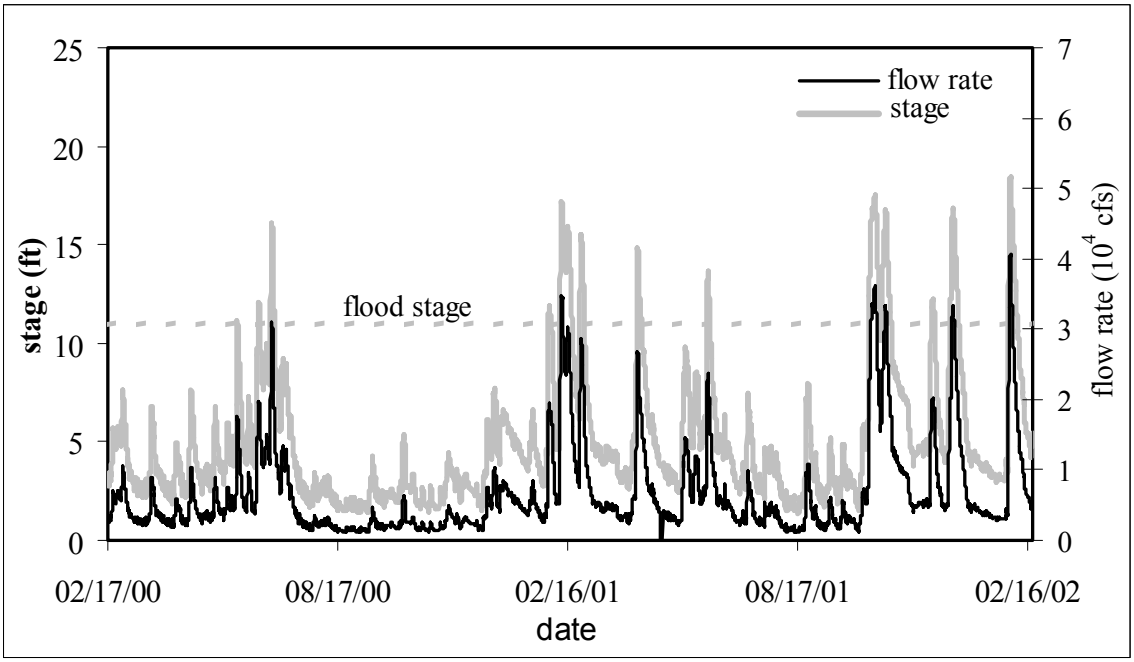

Fig. 2: Time series of stage and discharge for the Wabash River at Lafayette over the current project period (6/1/00-2/16/02)

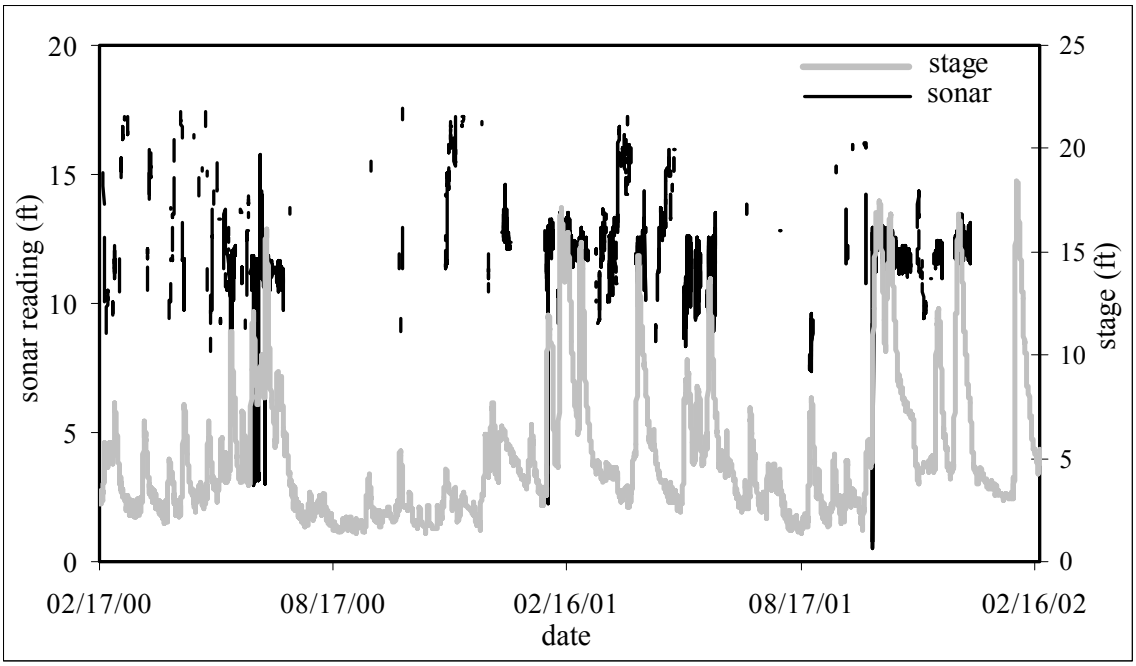

Fig. 3: Sonar device record over project period, compared with corresponding stage record

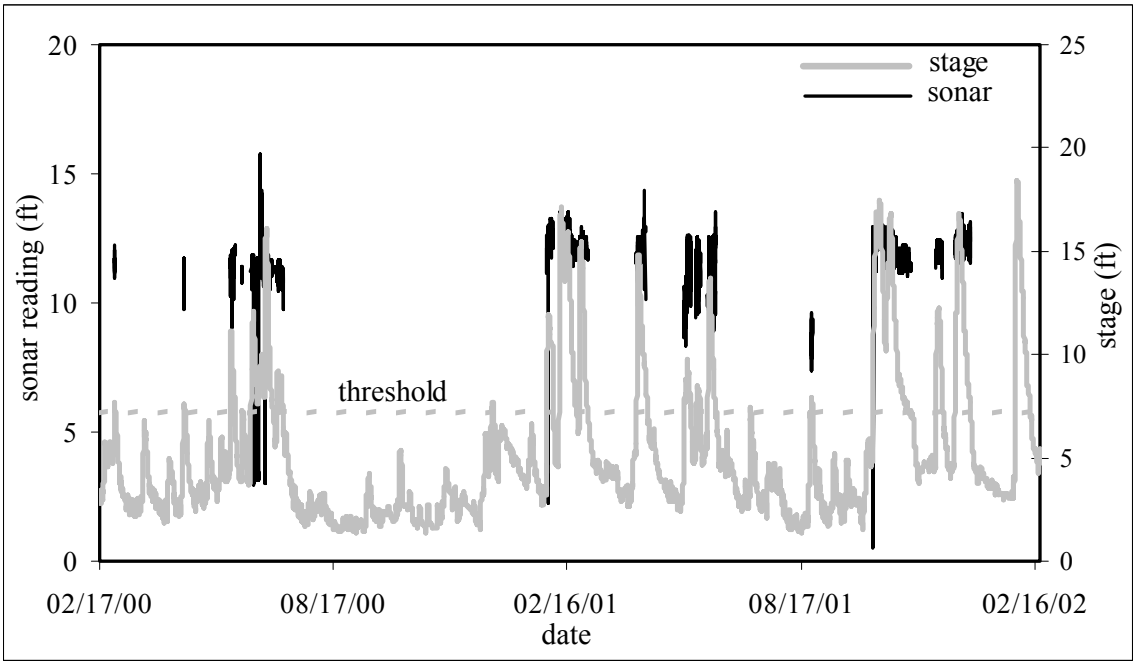

Fig. 4: Sonar readings in which those points that correspond to a stage less than a threshold value (7.25 ft) have been discarded

As a further test of the sonar device, a time series with much higher sampling rate (every two seconds instead of every hour) was recorded to check whether the erratic behavior of the data would still be seen. The sonar record over a period of approx. 90 minutes taken during the event of 2/16/01 is shown in Fig. 5. The readings are quite well-behaved,

exhibiting some expected noise, which however is contained within a rather narrow band (note that the scale of the ordinate has been expanded from the previous figures to emphasize the narrowness of the noise band), sufficiently narrow in fact that a physical trend can be discerned in spite of the noise. This suggests that the sonar device is operating as intended.

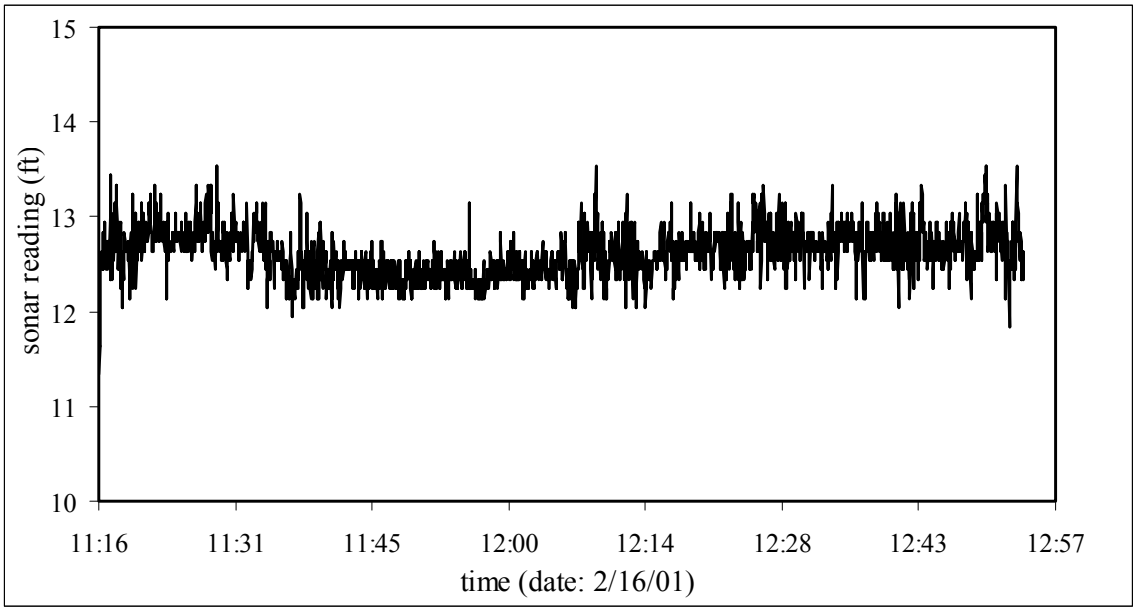

Fig. 5: Record of test of sonar device in which data were taken at a much higher sampling rate to check whether any evidently erratic behavior could be identified

The sonar data and hydrologic data

The overall view provided in Figs. 3 and 4 does not give any insight into the relationship between the sonar scour monitoring data and the hydrologic parameters (either stage or discharge) because large flow events last only for relatively short durations, and on a multiyear scale, appear as an undifferentiated blob. In this section, these larger flow events will be examined on a finer scale, thereby allowing a more detailed view of the correlation between flow events and scour-monitor data. An example of a record of flow event (stage) and sonar data is shown in Fig. 6 during the event of 5/28/00-7/12/00. The sonar (hourly) signal exhibits substantial 'noise', making it difficult to discern trends. For this reason, a simple 9-point moving-average filter has been applied to the sonar signal. The corresponding smoothed signal is shown in Fig. 7. The smoothing operation does tend to attenuate sharp peaks, which should be kept in mind in interpreting the smoothed data, but longer-term trends are easier to identify.

In general, a broad positive correlation between stage and sonar reading can be found. Higher stages imply larger discharges and typically larger mean velocities, so that a positive correlation would be expected. Except for Fig. 7, where some erratic behavior is seen (a sharp decrease in sonar reading, followed by a region of rather flat behavior), the other events all exhibit broadly similar longer-term changes in stage and in sonar reading. For the longest continuous sonar reading record (during the event shown in Fig. 8), the

sample correlation coefficient, *r*, between stage and sonar reading was found to be 0.86, which indicates a reasonably strong relationship between the two variables.

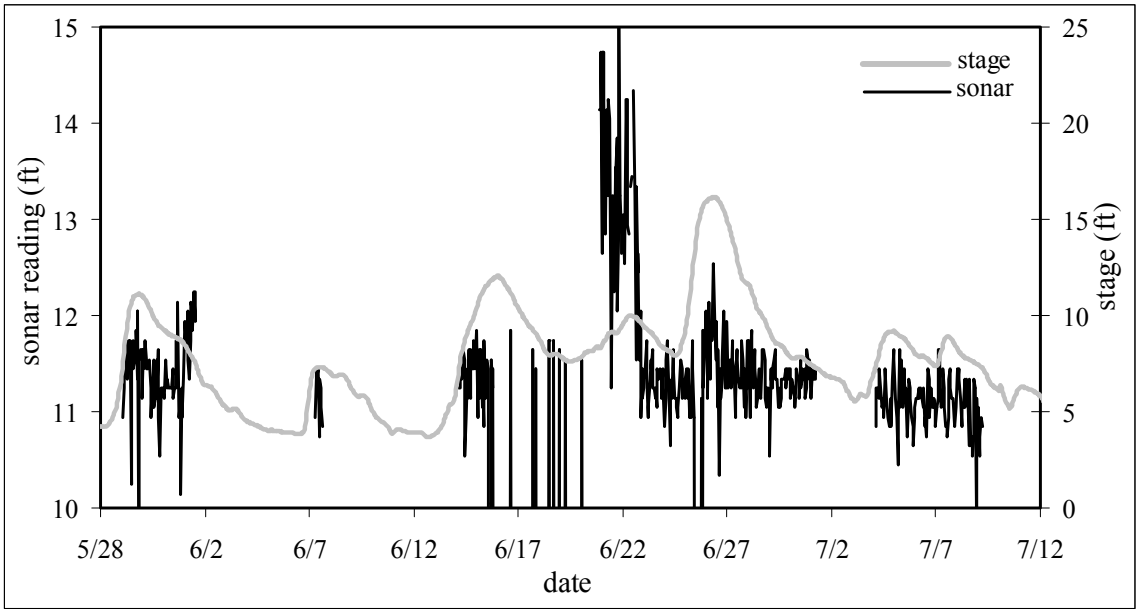

Fig. 6: The hourly sonar signal for the event of 5/28/00-7/12/00 plotted with the hourly stage signal.

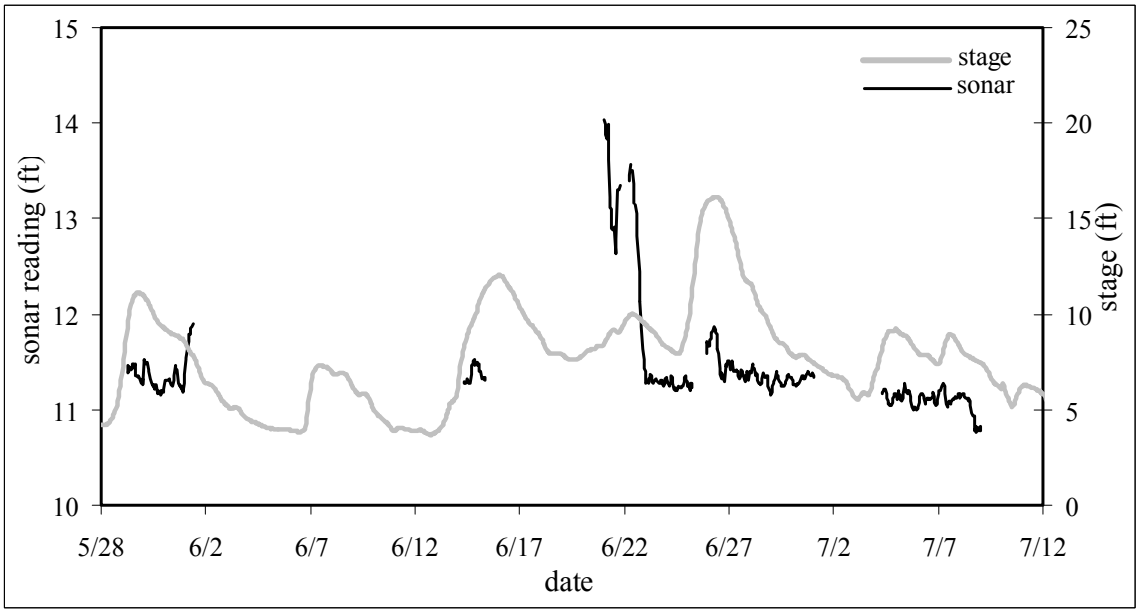

Fig. 7: Filtered signal from sonar scour monitor from 5/28/00-7/12/00, together with the corresponding stage signal

An interesting aspect, especially evident in Figs. 8 and 9, are relatively regular short-term (period of $\approx$16 hours) variations of the bed level. While these were hidden in the raw data, they are quite prominent in the filtered data, and do not seem to be strongly correlated with the longer-term variations in stage. It is conjectured that these reflect the pas-

sage of trains of bed forms, such as dunes, which would be present for a range of flows, *even in the absence of the pier*. This suggests that some care should be exercised in interpreting the sonar reading, since the scour-and-fill process is not necessarily solely associated with the scour around bridge piers. On the other hand, that the sonar reading is able to track the effects of known physical features such as bed forms gives further support to the credibility of the sonar data.

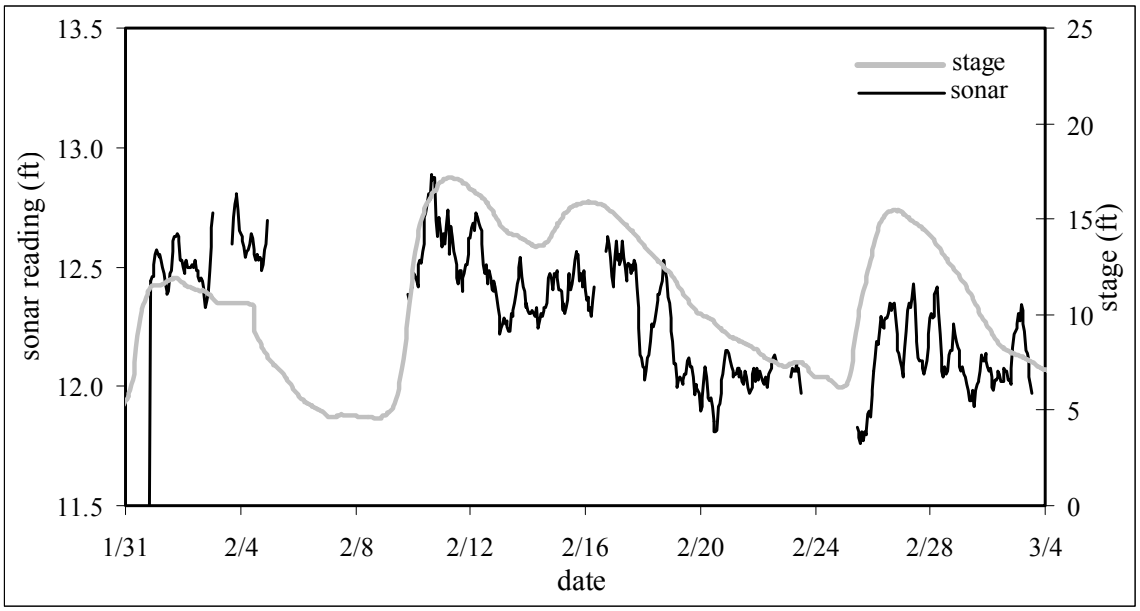

Fig. 7: Filtered signal from sonar scour monitor from 1/31/01-3/4/01, together with the corresponding stage signal

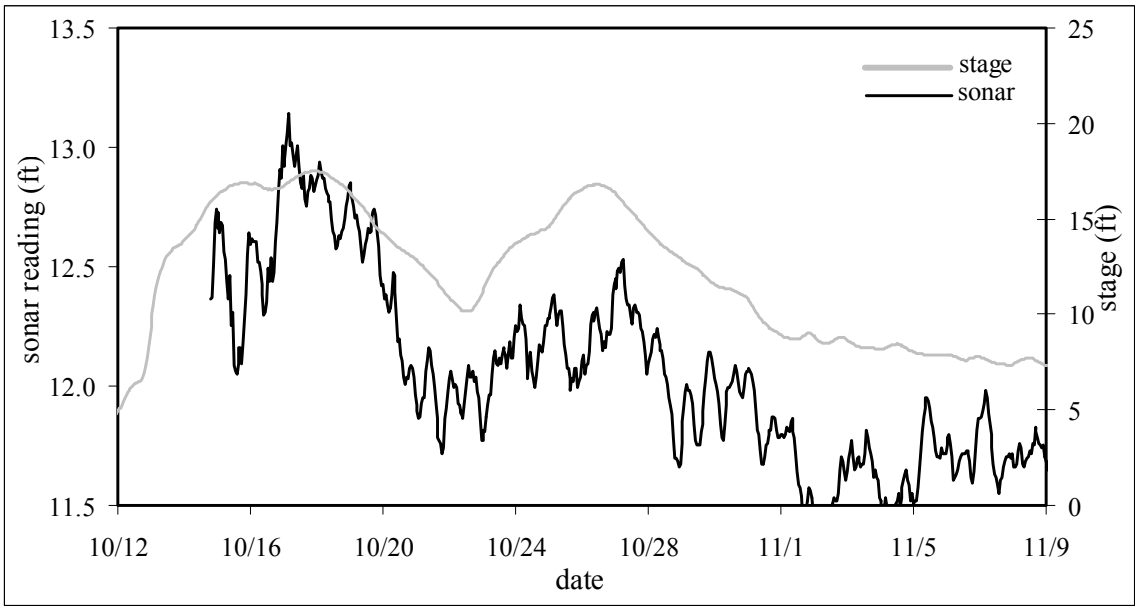

Fig. 8: Filtered sonar scour monitor signal from 10/12/01-11/9/01, together with the corresponding stage signal

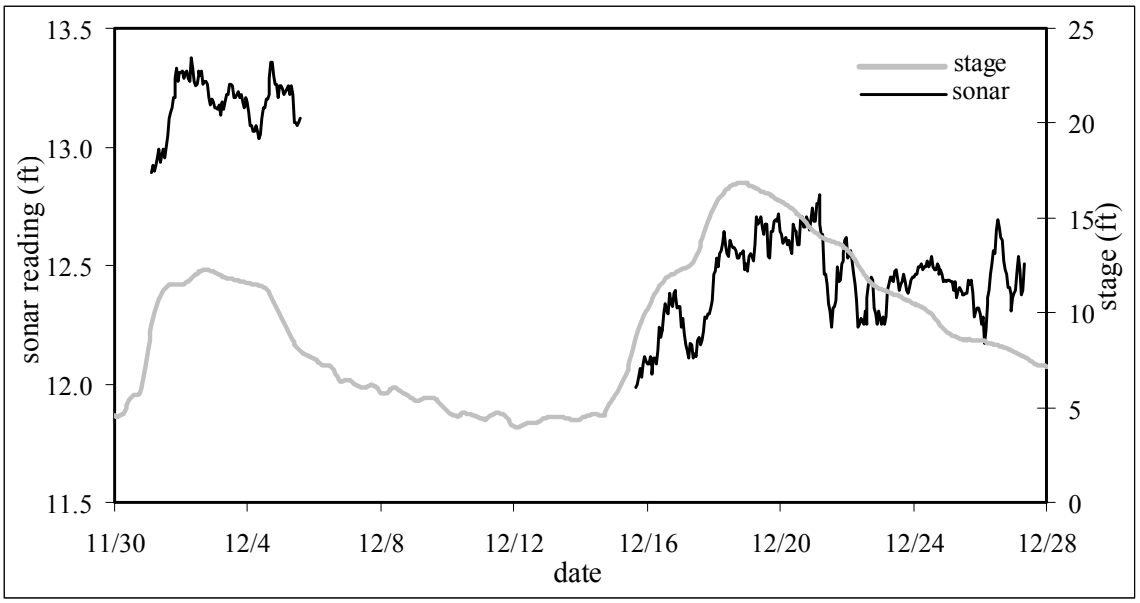

Fig. 9: Filtered sonar scour monitor signal from 11/30/01-12/28/01, together with the corresponding stage signal

Further discussion, conclusions and recommendations

Continuous scour monitoring using either a magnetic-collar device or a sonar device was tested during the course of the present as well as a previous project as a potentially useful tool in dealing with pier scour. The experience gained from these projects clearly show that practical difficulties, particularly the effect of floating debris, either by accumulation or by impact damage, limit the usefulness of these devices, and as such their successful deployment will require careful consideration. An alternative approach that has attracted the attention of INDOT Hydraulics Group (Merrill Dougherty, private communication) is a portable sonar device that would be deployed during flood events from the bridge deck by a trained operator. The following discusses the merits and problems of these different scour-monitoring options.

The magnetic collar: This device proved to be surprisingly robust, with respect both to damage as well as to operation. At the Wabash River site, it survived all but the largest event (1/1999), which also caused catastrophic damage to the sonar device. At the Wildcat Creek site, in contrast to the sonar device, it provided useful scour information even in the presence of sometimes severe debris accumulation. Its weak point in terms of damage susceptibility lies in the flexible hose conduit connection between the steel rod and the data acquisition/electrical box through which the data and electrical cables were routed. At the Wabash River site, this conduit was completely severed, while at the Wildcat Creek site, it was seriously damaged twice (and repaired once). A re-design of this connection could resolve or at least ameliorate this problem. For practical installations, the re-design that was under consideration, involving a rigid armored conduit effectively all the way to the steel rod, requires however relatively shallow flows (i.e., during dry months). For larger rivers, with the relevant pier in deep waters throughout the year, the cost of installing such a modified conduit may become prohibitive. It is also noted that the magnetic-collar device is still undergoing development, and a wireless

connection is a possibility in the future. With the present technology, and a re-designed conduit, the magnetic-collar device deserves consideration for scour monitoring at sites with shallow low-water flows and debris accumulation. Indeed, where debris accumulation is chronic, the magnetic-collar device may be the only possibility for scour monitoring.

The fixed sonar device In spite of the poor performance at the Wildcat Creek site, where essentially no reliable data was obtained because of chronic debris problem, the sonar device may nevertheless fill a useful niche. With the modifications made to the conduit and the housing, the sonar device has operated at the Wabash River site continuously without failure due to damage for over two years. The first set of modifications, namely only to the conduit, survived much larger events than that which caused the first failure. It is expected that, similarly, the second set of modifications, namely including a new housing for the sonar transceiver, will enable the modified sonar device to survive events larger than that which caused the second failure. Because no such event occurred over the last 2-year period, this has however not yet been confirmed in the field. As argued above, the data obtained over this period, when appropriately processed, are credible in exhibiting a strong correlation between hydrologic parameters, such as stage (or discharge), and bed levels.

For crossings over larger rivers with perennially deep flows, such as the Wabash River site, the practical advantages of the sonar device are undeniable. In such cases, debris accumulation tends to pose less of a problem. The deeper flows present difficulties in the installation of the magnetic-collar device, even if the original flexible-hose conduit is retained, and rules out entirely the re-designed armored rigid conduit. A further difficulty encountered where larger rivers are concerned that makes the use of a portable sonar device infeasible is the distance of the bridge deck to the water surface. In addition to these practical advantages, the sonar device also is the only device capable of providing a continuous record of *both* scour and fill.

The portable sonar device This device was not considered in either the current or the previous project, but has attracted some positive attention from INDOT personnel. The operating principle is exactly the same as the fixed sonar device, but would be deployed during a flood event from a bridge deck, by a trained operator. Because it is not permanently mounted in the stream, it would not be exposed to the same extent as the other two devices to physical damage and hence failure. This does not preclude the possibility of failure, e.g., that the device might be swept away during the event, but would presumably decrease the probability. Limitations should however be recognized. The presence of debris accumulation at a pier would still render any sonar device, portable or fixed, inoperable even if physically undamaged. Measurements would be extremely difficult if the distance from bridge deck to water surface is large, such as was the case for the Wabash River site. Because of the need for human intervention, the portable unit is likely more susceptible to error and inaccuracy in measurement, e.g., there may be difficulties in keeping the floating transceiver at a fixed location, and uncertainty as to whether the unit was deployed at the time when the scour hole had attained its maximum depth. On the other hand, it does not involve installation costs, and a single unit could be

used at various sites. A recent but considerably more costly development is a truck-mounted sonar device. Being more rigidly mounted, and combined with a more sophisticated automatic data acquisition, this version of the portable sonar device is likely to give more reliable measurements when used by properly trained personnel. Nevertheless, the general limitations of the more basic device already mentioned above would still apply to the truck-mounted device. Though the mobile sonar device, whether portable or truck-mounted, may be a useful tool when applied judiciously, the portable sonar device cannot be considered as a universal alternative to either of the two devices studied over the last five years.

Conclusions and recommendations

- The sonar device at the Wabash River site, in its redesigned heavily armored form, has operated continuously over the current project period without failure due to damage. During the current project period, several flood events have occurred, though none of very large magnitude. The sonar record has provided credible data regarding bed levels and hence local scour around the bridge pier.
- Each of the scour-monitoring devices has its own merits, and may be successfully deployed under appropriate conditions.
    - The magnetic collar device is the only option where debris accumulation is a chronic problem. Modifications to the conduit to make it more robust are highly recommended when feasible, namely, when shallow low-flow conditions make installations practical.
    - For large deeper rivers with high bridge decks, the sonar device permanently mounted on a bridge pier, again suitably modified with armored housing and conduit, is likely the only practical option.
    - For conditions other than those listed above, the portable sonar device may prove to be a somewhat limited option, offering some flexibility in deployment. A fixed unit, suitably armored, may however still be competitive with the portable unit, and depending on the particulars of the site, should also be considered.
- Scour-monitoring devices, *judiciously chosen* according to the above criteria, may serve a useful role as *one tool among others* in an overall strategy for managing problems associated with pier scour.

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