

RIVER FLOODING OBSERVATION UTILIZING REMOTELY PILOTED AIRCRAFT

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Abstract-The overland flooding of the Red River of the North is an annual event that results from abundant snowfall, extreme temperatures and river ice jams. Many small valley communities have not benefited from infusions of state or federal dollars to mitigate or remediate the effects of these events. The coping strategies consist of observation, forecasting, temporary dikes and evacuation. Scientists and researchers require more robust data sets that may facilitate the understanding of surface water hydrology in the region, the behavior and properties of snow and river ice, and the short and long term impact of annual flooding on agriculture, the major industry that supports the region. This paper describes the use of unmanned aircraft to obtain real time or near real time video evidence of the evolution of the 2010 Oslo, Minnesota flood, and to collect useful data for government organizations as they meet the demands of future flooding events.

Key Words: Floods, Environment, Surface Water Hydrology, Robotics, Snow Ice, Technology, Weather

1. Introduction

Annual overland flooding of major (and sometimes not so major) rivers in North America causes untold misery for millions of people and billions of dollars of damage to towns, cities, farmlands and public property. Several factors contribute to this phenomenon.

Landform factors include a relatively shallow and meandering river channel. A shallow channel holds less water and the meandering can cause flow to slow down as the channel makes its turns, causing overbank flooding. A gentle slope (averaging 0.5 to 1.5 feet per mile) inhibits channel flow and encourages overland flooding or water “ponding” (especially on even, saturated ground) in the basin. In addition the northerly direction of flow (flow in the Red River travels from south [upstream] to north [downstream]) becomes a critical factor in the spring when the southern (upstream) part of the Red River has thawed and the northern (downstream) part of the channel is still frozen. As water moves north toward the still frozen river channel, ice jams and substantial backwater flow and flooding can occur.

Weather factors include spring (snowmelt) floods that may follow above-normal amounts of precipitation in the fall of the year that produce high levels of soil

moisture, particularly in flat surface areas, in the basin. Freezing of saturated ground in late fall or early winter, before significant snowfall occurs, produces a hard, deep frost that limits infiltration of runoff during snowmelt. Other factors that also contribute are above-normal winter snowfall in the basin, above-normal precipitation during snowmelt, and above-normal temperatures during snowmelt.

Summer floods also occur as a result of above-normal or intense precipitation in the same area over a short duration from May through October. Saturated ground causes more runoff, and limited vegetative cover may lead to less absorption of water and more runoff.

Landform factors, combined with any or all of the weather factors, determine the severity of flooding. For example, below-normal fall precipitation combined with above-normal winter snowfall, above-normal temperatures during snowmelt, and above-normal precipitation during snowmelt can lead to significant flooding. In contrast, below-normal fall precipitation combined with above-normal winter snowfall, below normal temperatures during snowmelt, and little precipitation during snowmelt may cause only minimal flooding. Most of the catastrophic floods that have occurred in the Red River Basin (the last being in 1997, which led to the evacuation of Grand Forks, North Dakota) were caused by a combination of landform factors, and most or all of the weather factors affected the magnitude of those floods.

While the landform factors are well known, the weather factors are of course variable and difficult to predict with any degree of confidence. The residents and first responders in the areas affected by flooding are more or less at the mercy of both categories of factors, but still make efforts to mitigate the impact by monitoring the condition of the river and tributaries, particularly the behavior of the ice as it jams and melts, and by measuring the moisture content and depth of the snowpack. The technology described in this paper, small, unmanned aircraft with on-board sensors, is but one of several strategies that may be employed to gather the necessary data for analysis by the scientists, researchers and interested government agencies as they attempt to serve the needs of the communities impacted by overland flooding. The major challenges presented to the users of these devices are the technical limitations of the systems intertwined with the aviation regulatory system.

1. The Platform

The unmanned aircraft system chosen for this project was the Boeing/Insitu ScanEagle™, a catapult-launched and cable-recovered aircraft weighing approximately 44 pounds, equipped with on-board infrared and electro-optical cameras, an autopilot and two-way radio communication capability, which allows the aircraft to serve as a link to air traffic control facilities. (See Figure 1).



Figure 1. Boeing/Insitu ScanEagle™ UAS

One major advantage of the ScanEagle for this type of campaign is its “deploy-ability,” in that it does not require a runway for takeoff or landing. The authorization issued by the Federal Aviation Administration (“FAA”) allowed for the aircraft to be launched and recovered from any place within the authorized area, which allowed the pilot and support crew to move the equipment around for maximum coverage and to avoid the rising flood water that they were observing (see next section for discussion). The high-resolution cameras provided critical imaging that was offered to and gratefully accepted by local law enforcement agencies, first responders, city officials, federal agencies and the press.

2. The Regulatory Environment

The Federal Aviation Administration has taken the position, through policy statements and issuance of guidelines, that unmanned aircraft that are used for any purpose other than recreation (model aircraft, for example) come under the agency’s regulatory jurisdiction.* Thus, the operation of these aircraft for scientific or research purposes must be conducted in a manner consistent with the rules and standards set forth in the Federal Aviation Regulations. Since no unmanned aircraft system (“UAS”) can currently comply with many of those regulations, prospective operators must apply to the FAA for a Certificate of Authorization or Waiver (“COA”) to allow the operations, with certain restrictions and prohibitions attached. The process can take months, unless the proponent can make a case that an Emergency COA should be issued due to an imminent loss of life, and manned aviation assets are insufficient to address the emergency.

Remotely piloted aircraft by definition have no on-board pilot to perform what are known as “see-and-avoid responsibilities” (the duty of all pilots, even those flying commercial airliners at great altitudes, to look out the wind screen and remain vigilant for potential conflicts with other aircraft). Therefore, when operating outside of restricted areas (military operations facilities), special provisions must be made to ensure that a level of safety exists for the operations, equivalent to having a pilot on board the aircraft. In accordance with relevant regulations, the FAA declared that certain precautions would provide acceptable mitigation of the see and avoid requirement and must be complied with. Visual observers had to be utilized at all times except in Class “A” airspace (above 18,000 MSL), restricted areas, and warning areas. The observers could either be ground based or in a chase plane. The UAS had to remain within a lateral distance of no more than one (1) nautical mile and 1,200 feet vertically from the visual observer. The distances listed were the maximum distance, and at no time could the UAS be operated at a distance beyond the visual line of sight for the visual observer.

UAS pilots were required to ensure that there was a safe operating distance between manned and unmanned aircraft at all times in accordance with 14 CFR 91.111, *Operating Near Other Aircraft*, and 14 CFR 91.113, *Right-of-Way Rules*. Cloud clearances and VFR (visual flight rules) visibilities for Class E (uncontrolled) airspace would be used regardless of class of airspace. Additionally, UAS operations were advised to operate well clear of all known manned aircraft operations.

The dropping or spraying of aircraft stores, or carrying of hazardous materials (included ordnance) outside of active Restricted, Prohibited, or Warning Areas was prohibited unless specifically authorized in the Special Provisions of the COA.

The pilots were, at a minimum, required to pass the aeronautical knowledge test for private pilots, to keep their aeronautical knowledge up to date, and to hold a second-class medical certificate. Observers were also required to hold a second-class medical. For operations beyond line-of-sight on an instrument flight plan, the pilot had to be a certified private pilot, and have an instrument rating for the category and class of aircraft flown. (Ironically, there is no designated category or class of UAS in the regulations, so this requirement is ambiguous at best, and meaningless at worst.)

There are several other regulatory requirements that go along with the COA for such an operation, all directed towards ensuring the highest level of safety possible. Two-way radio communication and data link integrity, contingency plans in the event of system failure or conflicting aircraft in the area, coordination with Air Traffic Control and other agencies and aircraft operators (such as news helicopters, search

and rescue aircraft, and sightseers), and position-locating transponders were all diligently planned for and monitored.

The restriction to line-of-sight operations is intended to allow the ground observer to know the approximate location of the aircraft so that any potential conflicting traffic can be seen with sufficient time to determine whether a collision is imminent or even possible, and to take necessary evasive action with the UAS in response thereto. However, with a system such as ScanEagle, which is capable of sustained operations far in excess of what even a typical general aviation manned aircraft is able to maintain (over 24 hours), the line-of-sight restriction did not allow for anywhere near the design capability of the system.

The use of remotely piloted aircraft for the purpose stated in this subject project is controversial and rarely approved by the FAA. There are many reasons for the dearth of successful operations of this type, but the most prominent are lack of confidence by the regulators in the safety of the systems with respect to the see-and-avoid requirement, the operational integrity of the various components of the system (power plant, data links, communications, airframe, power requirements for the on-board sensors), and public perception that the systems are not up to aviation safety standards. The FAA was sufficiently interested in this particular operation to send a team out to the flood area to observe flight operations and view the data that was being collected by the sensors. The expectation of the proponents of this COA was that, upon successful completion of the data collection process, the COA could be renewed in anticipation of another flood event in the spring of 2011 (COAs are issued for no longer than one year, and often for considerably less than that, depending upon the intended use of the UAS-in this case it was for 83 days).

3. The Science Goal

Monitoring overland flooding in the Red River Basin has been a local pastime for over a century. The cities of Grand Forks and Fargo, North Dakota, and Oslo, Minnesota, have each experienced more than one major flood event that has inflicted tremendous damage to the communities, the surrounding agricultural land, the social infrastructure and the economies of the region. Remediation and mitigation strategies such as diversion channels and dike systems have alleviated some of the threat, but each year presents a new challenge to smaller communities such as Oslo that don't readily reap the benefits of large infusions of disaster relief and financial support from state and federal governments. They are left with the tools available to agencies such as NOAA, USGS and FEMA to make predictions and issue forecasts of flooding with sufficient warning to allow for sand bagging, temporary diking and even evacuation. The

USGS has mapped the Red River flood patterns for decades. (Figure 2).

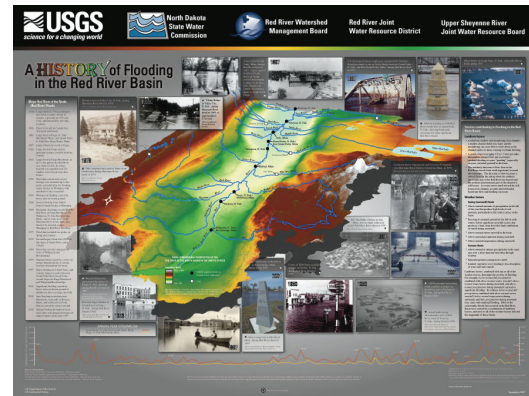


Figure 2. United States Geological Survey chart of The History of Flooding in the Red River Basin.

As winter was drawing to a close and early spring of 2010 was around the corner, predictions of major flooding in the Red River Basin were made by USGS. (Figure 3 purple area of chart).

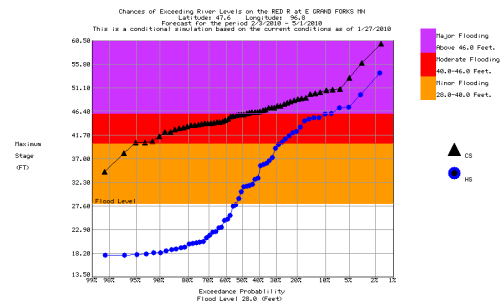


Figure 3. Forecast of major flooding greater than 50% probability 2/3/2010-5/1/2010.

The forecast for a 50-90% probability of moderate to major flooding around Oslo, Minnesota was made for the same period. (Figure 4).

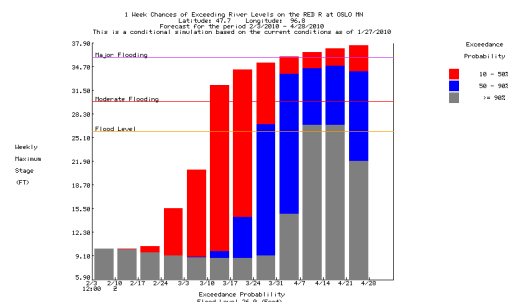


Figure 4. Blue and Red bars represent 50-90% probability of moderate to major flooding 2/3/2101-4/28/2010.

NOAA disseminated real-time charts based upon their observations, and contact with NOAA's staff convinced the research team that aerial observation of the build up of ice jams at certain critical locations near Oslo (around the bridges) would be of benefit. A sample chart is represented in Figure 5 below. This chart showed the actual readings for the period from February 1-4, 2010, level 10.3 ft., with flood stage at 26.0 feet. With everything still very much frozen on the Red River on February 4, 2010, the models predicted major flooding when warmer weather initiated the snow and ice melt.

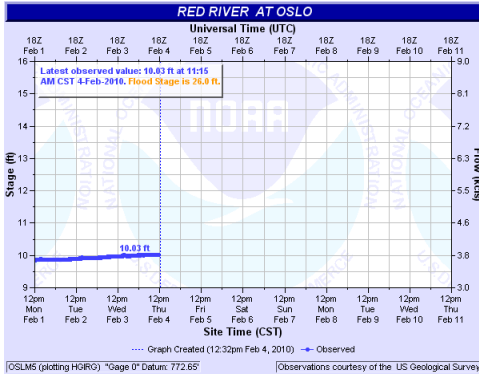


Figure 5. Real time chart of flood level as of February 4, 2010.

Based upon the observations and the models a flood warning was issued for the Red River Valley around Oslo in mid-February of 2010. An application for a Certificate of Authorization and Waiver under and emergency or expedited procedure was made shortly thereafter, and was processed and approved by the FAA in less than three weeks. The area to be observed with ScanEagle's EO/IR cameras was designated on an aeronautical sectional chart (Figure 6) and a Google Maps© satellite image (Figure 7).

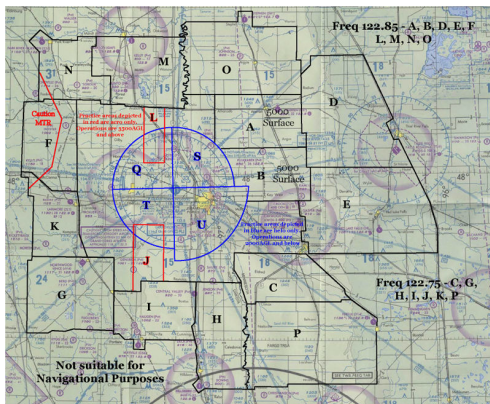


Figure 6. Aeronautical Sectional Chart showing target area around Oslo, MN.

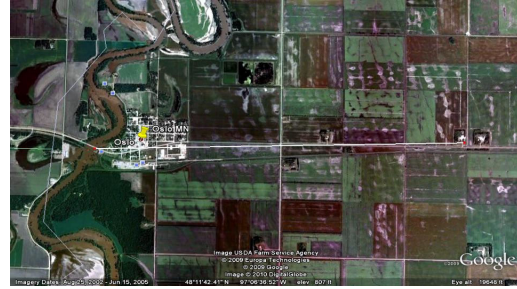


Figure 7. Satellite photo of Oslo, MN and bridge.

The campaign was highly successful, in that it demonstrated the capabilities of a small unmanned aircraft system in providing real-time or near-real-time video and still image data to interested parties, particularly the citizens of Oslo, Minnesota and the surrounding area, as they fought their annual battle to try to tame the Red River and minimize social and economic damages to their community.

4. Conclusion

The evolving and emerging unmanned aircraft technology offers many advantages to the scientist or researcher desiring to collect useful data in harsh and inhospitable environments. The risk to humans operating the systems is relatively low (there have been no reported or known fatalities from the operation of unmanned aircraft, aside from their well-known military use in theaters of war). In many cases they are less expensive to operate than manned aircraft. The greatest challenge to all potential users, whether in domestic U.S. airspace, or over international waters, is the lack of any uniformity in regulations at a national or international level that may impact UAS operations. Efforts are under way around the world, primarily in the U.S., the U.K., parts of Asia, Scandinavia, and Australia, to harmonize existing regulations, to bring the world's dominant civil aviation authorities to the table to hammer out agreed upon standards and regulations, and to promote the peaceful use of remotely piloted systems by the scientific community. The Oslo, Minnesota project was a small, incremental, but successful step towards realizing that goal.

References:

*72 FR 6689, Volume 72, No. 29, February 13, 2007 (Interim Operational Approval Guidance 08-01)

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Acknowledgements:

ScanEagle image courtesy of Benjamin Trapnell, Grand Forks, ND.