International Perspectives in Water Resource Science and Management: Living with Floods The Netherlands & United Kingdom The University of Iowa, Summer 2010

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CARDIFF

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International Perspectives in Water Resources Management is a study abroad program initiated in 1997 by IIHR – Hydroscience & Engineering that offers intensive and in-depth exposure to students about issues impacting water resources worldwide. Each year, the program focuses on a different world region, preparing students for careers in a global marketplace. The course in the Netherlands and United Kingdom was organized by IIHR in cooperation with UNESCO-IHE (Delft), University of Bristol, Cardiff University, and Imperial College London.









International Perspectives in Water Resource Science and Management:

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Activities

Introductory Meeting (02/23/10) Course history Introduction to the 2010 course Financial aspects

Inaugural Meeting (04/08/10)

The class of 2010

Course Itinerary

Sharing practical experience and tips for traveling and living in Holland - Aubree Miller, Office for Study Abroad Discussion of the project topics and assignments

Pre Departure Meeting (04/29/10)

Course itinerary and logistics details More instructions and tips - Aubree Miller, Office for Study Abroad Discussion of the project topics and assignments Student interactions

<u>Course Tour (5/17/10 - 5/31/10)</u> Course Tour

Project Development (6/1/10 - 7/30/10) Projects









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Course Tour





May 15 - Arrival in Delft May 16 - Arrival, Keukenhof Gardens May 17 - Course Logistics, Delft Tour May 18 - Belgium May 19 - Delta Works May 20 - UNESCO-IHE May 21 - Deltares, TU Delft May 22 - Amsterdam May 23 - Amserdam, Arrival in Bristol May 24 - Course Logistics, University of Bristol May 25 - Cardiff University, EA Wales May 26 - HR Wallingford, Halcrow May 27 - EA Midlands, Tewkesbury, Bewdley May 28 - Arrival in London, Imperial College London May 29 - Thames Barrier, Greenwich May 30 - London









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Course Tour

May 15 - Delft Arrival



A select few have made it to the Netherlands without delays related to volcanic ash. The day starts with a train ride from Amsterdam to Delft where the group is to assemble and stay for the week. They then settle into their housing complex.

With the housing complex situated in the middle of the old city centre of Delft, the group is able to explore the historic area.









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Course Tour

May 16 - Arrival, Keukenhof Gardens





More group members arrive throughout the day. With the course not having yet officially started, the group continues to explore Delft. Later in the day, members travel to the Keukenhof Gardens, located between Delft and Amsterdam. The Keukenhof Gardens contain the world's largest, most diverse, and most beautiful expanse of flower displays.



In the evening some group members join to enjoy an Iranian dinner back in Delft.









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Course Tour

May 17 - Course Logistics, Delft Tour



The first official day of the course started bright and early with a group meeting at UNESCO-IHE to discuss course logistics. Group members discuss their contributions to course projects. Lunch in the UNESCO-IHE cafeteria and courtyard follows where the group has a chance to meet some of the local professors.





After lunch, members are free to explore the area again. One part of the group decides to take the tram to Den Haag where they explore its large beach while eating ice cream and playing frisbee. The rest of the group stays in Delft to visit the Old Church.









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Course Tour

May 18 - Belgium



The day starts with a bus ride into Antwerp, Belgium where the group stops at Flanders Hydraulics (Waterbouwkundig Laboratorium). Here they are presented with various flood defense and research projects taking place in the Flanders region of Belgium. This research institute also contains a towing tank facility where the performances of model ships are tested. The group is able to see a model ship in action as it is towed through the channel.





The group then buses further south into Belgium to a small town called Temse on the Sheldt River/Estuary. It is here where they board a river boat and begin their journey downriver back into Antwerp.



Mid-voyage, the group stops along a section of the river at which the Sigma River Project is taking place. At a visitors center the group is presented with how the water retention system is managed and how it is used to reduce inland tidal levels.





Once re-boarded onto the boat, the group continues the trip into Antwerp. After disembarking, group members are free to explore Antwerp where they spend the remainder of the day. A late dinner is had at an Indonesian restaurant back in Delft.









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Course Tour

<u> May 19 - Delta Works</u>



The three barriers connecting the mainland to two artificial islands (Neeltje-Jans) in the Eastern Sheldt inlet make up part of the Delta Works flood defense project. The group begins at the visitor center observing exhibits and learning about the construction of the barriers. A tour out to one of the barriers follows.



The group then travels to the Maeslantkering which is one of the largest moving structures on Earth and is located on the Nieuwe Waterweg waterway, protecting the Rotterdam area from storm surge. The group tours the facility and grounds.



After visiting the Maeslantkering, the group stops at the nearby beach to enjoy some freshly fried mussels.











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Course Tour

May 20 - UNESCO-IHE



The day starts at UNESCO-IHE where Dr. Demetri Solomatine presents his research in hydroinformatics and Dr. Ann van Griensven presents her research in river basin management. Flood modeling, warning systems, and uncertainty and risk analysis are also discussed. Allen has a chance to present the Iowa Flood Center to UNESCO-IHE and Marian presents Hydrology for the Environment, Life and Policy (HELP).





In the afternoon the group splits up to explore the area once more. Some group members pay a visit to the local market near the New Church. They then climb to the top of the church's steeple where they enjoy marvelous views of Delft.



Other group members tour the Leger Museum where they see the world's largest collection of weapons from around the world. They then take the train to the Nation's capital, Den Haag, with the famous Escher museum being the target destination. It turns out the museum is closed so group members explore the town instead.









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Course Tour

May 21 - Deltares, TU Delft



The day begins at **Deltares**, a research facility in Delft. After having coffee in the architecturally stunning lobby the group is presented with the work of Dr. Arthur E. Mynett. A tour of the experimental and modeling laboratories follows. Lunch is served in the Deltares cafeteria.





After lunch the group walks to the TU Delft campus. Here they tour the Laboratory of Fluid Mechanics.



A stroll back through the Delft city centre follows. The group once again explores the town's night life in the evening.









International Perspectives in Water Resource Science and Management: Living with Floods The Netherlands & United Kingdom The University of Iowa, Summer 2010

Course Tour

May 22 - Amsterdam





Arriving in Amsterdam by train, the group unloads at the Lloyd Hotel and Cultural Embassy. The day is spent exploring the sights and sounds of Amsterdam. Highlights include a canal tour, the Rijksmuseum, and Leidseplein. The group also enjoys the wild nightlife later in the evening.









International Perspectives in Water Resource Science and Management: Living with Floods The Netherlands & United Kingdom The University of Iowa, Summer 2010

Course Tour

May 23 - Amsterdam, Arrival in Bristol



The day is free for sightseeing in Amsterdam.





In the evening the group flies to Bristol and arrives just in time to see the sunset. Upon arriving at their beautiful housing in the Burwalls Center the group discovers they are right next door to the world famous Clifton suspension bridge overlooking Bristol. Members cross the bridge into Clifton to have some late night fish 'n chips.









International Perspectives in Water Resource Science and Management: Living with Floods The Netherlands & United Kingdom The University of Iowa, Summer 2010

Course Tour

May 24 - Course Logistics, University of Bristol



The first full day in Bristol, the group enjoys an English breakfast at the Burwalls Center and then is given the privilege of using the Garden Room as a meeting place.



After some course logistics group members have a couple of hours to explore the Clifton Suspension Bridge and surrounding park area next door.





After exploring the nearby Clifton Suspension Bridge and surrounding area, the group assembles at the University of Bristol as guests in the Geography Department and the Civil Engineering Department. Professor Paul Bates introduces the local students and the group learns about the multitude of projects taking place at the institution which include evapotranspiration estimation using NWP, hydroinformatics, rainfall forecasting, hydrologic modeling, remote sensing, GIS and flood estimation, and non-structural flood mitigation. The evening is spent at a nearby park.









International Perspectives in Water Resource Science and Management: Living with Floods The Netherlands & United Kingdom The University of Iowa, Summer 2010

Course Tour

May 25 - Cardiff University, EA Wales



The group heads to Wales to visit the Hydro-Environmental Research Centre at the Cardiff School of Engineering. The research highlights here concern the proposed Severn Barrage which will serve as a flood defense as well as tidal power.





Although a late bus arrival shortens the excursion, the group still has a chance to hear some presentations, take a brief walk around the campus and downtown area, and visit Environment Agency Wales. Marian requested a new bus driver for the following day. The busy day ends in the beer garden of a Bristol pub.









International Perspectives in Water Resource Science and Management: Living with Floods The Netherlands & United Kingdom The University of Iowa, Summer 2010

Course Tour

May 26 - HR Wallingford, Halcrow



After another lovely breakfast the group meets their new favorite bus driver, Andy. The group buses through the countryside to HR Wallingford, a well known independent water management research and consulting firm, located between Oxford and London. The group is presented with current projects and tours the scale model facilities.



On the way back to Bristol the group stops at Halcrow, a well known firm working in flood risk management. The well kept landscaping of both facilities' grounds are noteworthy. At the end of the day TJ and Sam feel the need to work out.









International Perspectives in Water Resource Science and Management: Living with Floods The Netherlands & United Kingdom The University of Iowa, Summer 2010

Course Tour

May 27 - EA Midlands, Tewkesbury, Bewdley



The day starts with a bus ride to the Environment Agency Midlands West Area where the group is presented with flood defense research from the facility. Topics include the forecasting & warning system, flood risk management, and exemplification of public information on a flood event.



The group is then taken to The Severn Ham in Tewkesbury where they take a walk along the canal where a recent historical flood took place. A fabulous lunch is then enjoyed at Gupshill Manor in Tewkesbury.





After lunch the group travels to Bewdley where they are shown the demountable and temporary flood defense barriers.









International Perspectives in Water Resource Science and Management: Living with Floods The Netherlands & United Kingdom The University of Iowa, Summer 2010

Course Tour

May 28 - Arrival in London, Imperial College London



The last morning in Bristol, the group discovers a fox sunning himself on the grounds of the Burwalls Center.



After the bus ride to London, the group settles into their housing at the Cranley Gardens Hotel in the affluent Kensington area of London. Once unpacked, the group visits the Urban Water Research Group at Imperial College London and has an opportunity to meet faculty and students over lunch in the school cafeteria. Later, Individuals from both schools present their research and Allen introduces the Iowa Flood Center. Topics included modeling, management, and prediction of urban floods. An informal reception proceeds.



Upon leaving campus, the group members settle into their hotel rooms and have a chance to explore their posh surroundings.









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Course Tour

May 29 - Thames Barrier, Greenwich



The last day the entire group is together includes a boat tour down the Thames River to the Thames Barrier.





The afternoon is spent seeing sights such as the Greenwich Market, the Tower of London, London Bridge Experience, and Tower Bridge.



The day concludes with an Indian dinner in Picadilly Square.









International Perspectives in Water Resource Science and Management: Living with Floods The Netherlands & United Kingdom The University of Iowa, Summer 2010

Course Tour

May 30 - London





The course has come to a close. The group has the day to explore London. Sites include the Houses of Parliament, Buckingham Palace, Westminster Abbey, Hyde Park, Kensington Palace, and Wellington Arch.








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Participants

The Netherlands & United Kingdom The University of Iowa, Summer 2010

Living with Floods

International Perspectives in Water Resource Science and Management:

<u>Marian Muste</u> Faculty Member IIHR

<u>Allen Bradley</u> Faculty Member IIHR



<u>Fabienne Bertrand</u> Graduate Student M.S. in Civil and Environmental Engineering

Emphasis: Environmental Hydraulics

<u>Sam Boland</u>

Graduate Student Seeking M.S. In Civil and Environmental Engineering Emphasis: Containment Hydrology

<u>Shane Cook</u>

Graduate Student Seeking M.S. Mechanical Engineering Emphasis: Ship Hydrodynamics



Luciana Cuhna

Graduate Student

Seeking Ph.D. in Civil and Environmental Engineering Emphasis: Flood forecasting using remote sensing information

<u>Dan Gilles</u>

Graduate Student Seeking M.S. in Civiil and Environmental Engineering Emphasis: Numerical flood modeling

Zach Hingst

Graduate Student Seeking M.S. in Urban and Regional Planning Emphasis: Transportation and land use

Kyutae Lee

Graduate Student Seeking Ph.D. in Civil and Environmental Engineering Emphasis: Uncertainty Analysis in Measurement and Modeling, flood modeling and flood risk analysis



<u>TJ Middlemis-Brown</u> Graduate Student Seeking M.S. in Civil and Environmental Engineering Emphasis: Water Resource Engineering

<u>Sudipta Mishra</u>

Graduate Student Seeking Ph.D. in Civil and Environmental Engineering Emphasis: Water quality and hydrological modeling, Hydro informatics



Matt Moore

Graduate Student

Seeking M.S. in Hydraulics and Water Resources Program Emphasis: Flood Modeling and inundation mapping

Maria Perez Graduate Student Seeking Ph.D. Emphasis: Water Resources Engineering

<u>Evan Roz</u>

Graduate Student Seeking M.S in Industrial Engineering Emphasis: Computational Intelligence/Intelligent Sytems



Mike Schaefer

Graduate Student M.S. in Environmental Engineering

Taryn Tigges Undergraduate Student Seeking B.S. in Civil and Environmental Engineering









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International Perspectives in Water Resource Science and Management: Living with Floods The Netherlands & United Kingdom

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Projects

The best course projects were awarded with Special Project Prizes. These awards were made possible due to a donation provided by Greg Thomopulos (President, Stanley Consultants, Inc). This contribution (the first of the kind for this course) is greatly appreciated. The Special Project Prizes were shared with the Iowa Flood Center through a specially dedicated seminar

on December 3rd, 2010.

Course Website Shane Cook Taryn Tigges

Evaluation and Comparison of a Short-Term International Engineering Course An assessment of the international course and comparison of Europe 2010 to Egypt 2008-2009. Fabienne Bertrand Mike Schaefer

Sam Boland Zack Hingst

Living with floods: Effects of land-cover changes on flood risk A summary of ways flood risk is estimated, how model results are presented to decision makers and to the general public, and what the group learned at the different institutions visited in Europe on flood management and land use.

Luciana Cunha Maria Perez

Living with Floods

A report emphasizing the importance of controlling, coexisting, and responding to foods. TJ Middlemis-Brown

Modeling synthesis in hydro-science across continents; European perspectives and American adaptation: Lesson learned and looking forward The mission of the proposed study is to learn and understand existing hydro-synthesis approaches and to make observations and recommendations in dealing with future challenges in hydro-science.

Sudipta Mishra

Hydroinformatics: Data Mining's Role in Hydrology and a Virtual Tipping Bucket Framework Motivated from Studies Abroad This paper gives a brief overview of hydroinformatics, some applications of data mining in hydrology, lessons learned in the IPWRSM course, and the framework and preliminary results of virtual tipping buckets, as well as future research directions inspired the study abroad. Evan Roz

Review of Hydraulic Flood Modeling Software used in Belgium, The Netherlands, and the United Kingdom A review of software either created by or used by the groups visited on the trip, including Flanders Hydraulic Research, Deltares, EA Wales and EA Midlands, and the University of Bristol.

Dan Gilles

Matthew Moore

Food Risk Management

A summary of the main concepts of flood risk analysis, why it is needed, how it can be implemented, and what kinds of software tools are available up to date. Kyutae Lee

International Perspective in Water Resources Science and Management Evaluation and comparison of a Short-Term International Engineering Course



Michael Schaefer, Samuel Boland, Fabienne Bertrand, Zachary Hingst, and Marian Muste IIHR-Hydroscience & Engineering The University of Iowa, Iowa City, IA 8/21/2010

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	Abstract International Perspectives Background Evidence of study abroad programs' impact on education A Unique classroom: The Netherlands – United Kingdom 2010 Results of Survey Conclusion References

1 Abstract

The International Perspectives in Water Resource Management (IPWRM) course is steeped in a rich history of international experiences that have been provided to the graduate students of IIHR, and more recently, the greater academic community of the University of Iowa. Recognizing the need to expose students to the international facets of the engineering and research workplace, the IPWRM course aims to provide all of the benefits of a traditional study abroad course while overcoming the obstacles to enrollment that result in under-representation of engineering students. This year's excursion is provided as an example of how the course is a unique experience, and the results of surveys assessing the impact of the class are presented. The surveys corroborate the fact that the IPWRM course presents valuable international experiences in the form of a short-term study abroad program that accommodates the academic needs of engineering students.

2 International Perspectives Background

IIHR—Hydroscience & Engineering (IIHR), formerly the Iowa Institute of Hydraulic Research, is a world renowned research institute with a distinguished 90-year history in fluid mechanics, water resources, engineering, and hydrology (Mutel, 1998). The institute includes expertise in nearly all areas of hydroscience, with research foci ranging from ship hydrodynamics to fish passage around hydroelectric dams. The common factor linking many of IIHR's research and education areas is complementary expertise in field observational research, laboratory modeling, and computational modeling. Also distinctive to IIHR is its international flair, with faculty and research engineers hailing from 13 countries and its 75 students from 15 different countries (2008-2009 academic year). Thus it is appropriate that IIHR take the lead in offering students a unique international academic experience.

The University of Iowa course –International Perspectives in Water Resources Planning" (henceforth –IP") was created in 1997 as an initiative of IIHR's then director V.C. Patel (Mutel, 1998). It was developed in response to: 1) the increasing need for engineers and scientists to have a global perspective of water resources challenges; 2) the need for engineers and scientists from across the world to work together to develop solutions to our global water resources challenges; and 3) the lack of short-term, affordable international experiences available to engineering students.

Since its inception, IP has taken 124 students on nine different international experiences (India, 1998; Taiwan & Japan, 1999; China, 2000; Eastern Europe, 2001; Argentina & Brazil, 2003; Turkey, 2005; China, 2007; and Egypt, 2008-2009; UK and Netherlands 2010) to introduce them to the realities and complexities of global water and environmental issues. The course seeks to provide in-depth exposure to technical, historical, cultural, social, economic, environmental, and ethical issues and complexities influencing major water resource projects in countries outside of the U.S. The course participants, structure, and unique itinerary make IP a

stand-alone class that goes beyond the technical aspects of engineering, putting water resources engineering within the context of a different culture.

Most IP registrants are graduate students in The University of Iowa (UI) College of Engineering; however, students from other disciplines (generally liberal arts programs), engineering upperclassmen, and young engineering professionals also take IP. In addition, students from eight other domestic universities and colleges and from three international universities have participated in IP. Instructors for the course have also come from outside engineering, included faculty from geology and law. Thus, IP has become a truly international *and* multidisciplinary course, exposing students to new cultures while they interact with a diverse student and faculty group.

The course structure makes each offering unique. Prior to the international experience, students attend a series of seminars and presentations covering the region's culture, history, politics, and other factors relevant to the region. These presentations, which may include speakers from the host country, offer important background and context for the international component.

The international experience includes several specific components during an intense two to three week tour of the host country or region to better understand the complexity of issues that impact planning and execution of water projects in the region. First are visits to a variety of different water resources structures and laboratories. Advance arrangements are made for behind-the-scenes tours of these facilities and to interact with local engineers for discussion of their unique challenges. IIHR's vast network of research partners and alumni are often key to making these arrangements. Second, each tour includes an opportunity for students to meet and interact with engineering students and faculty at one or more universities. This includes formal time together (which includes a presentation about the UI by course participants) and unstructured time interacting with each other.

Each IP participant is also required to complete a group project. These projects vary depending on student interests, but generally include: development of a post-trip web site, presentation materials to deliver in the host country, and research papers focusing on relevant water resources issues of concern to the world region of the course.

3 Importance and Impact of Studying Abroad

Overview

Globalization and internationalization have become commonplace terms across all sectors of the economy, and the engineering field is no exception. While these words embody a broad variety of issues and opportunities, a major concern is that along with these terms come new obstacles that must be met with appropriate education and experience. This need has been identified by major institutions and deemed a high priority in research and education (NSTC,

2000; NSF, 2004). The Accreditation Board for Engineering and Technology (ABET) has mandated that one of the expected outcomes of a degree in engineering is that –graduates understand the impact of engineering in a global and societal context" (DiBiasio and Mello 2004). Study abroad programs have been proposed as a source for this new need, but a band-aid approach will not be sufficient for fitting the unique requirements of engineering curricula; study abroad programs must be adjusted to accommodate the typically highly regimented schedules of engineers' academic careers. Short-term study abroad programs have been shown to be appropriate and will likely become the new standard in preparing students for the global challenges that await them.

Global Context

The challenges have been prefaced as global for many reasons, including the facts that the global economy and national economies have become almost completely co-dependent and workplaces both inside and outside the United States have increasingly diverse multiculturalism. Additionally, the global economy has become ever more dependent on -knwledge products" and highly educated personnel for growth which subsequently has led to global capital investing heavily in knowledge industries such as higher education and advanced training (Altbach and Knight 2007). This has created a demand for engineers that are able to provide innovation to meet the expectations of global capital, which will likely place them in scenarios where they must address problems that are outside of the context of their immediate environment. Many industries rely on innovation to keep a competitive edge in an economy driven by knowledge products. Cultural and ethnic diversity foster creativity and recognize opportunity; diverse groups are more innovative and effective, which is crucial in today's international markets (Lohmann, Rollins and Hoey 2006), (Berkey 2010). The ability to work within culturally and ethnically diverse groups unfortunately does not come naturally to everyone, and can always be aided by previous experiences. Thus a growing pressure to expose students to international settings has been acknowledged by higher education institutions.

It is generally acknowledged that there is a need for engineering graduates to have a global competence and the ability to work comfortable in a transnational environment (Lohmann, Rollins and Hoey 2006). Even if students do not expect to leave the borders of the United States, 17 percent of engineers working in the U.S. are foreign born, suggesting the multicultural workplace is near unavoidable. (Mahroum 2000). And while students may not foresee leaving the borders of their country, the truth is that the international migrations of engineers are largely dominated by push and pull economic factors which are principally out of their control. It is argued that this migration typically complements local talent due to existing differences in aptitude and methods of study between countries (Mahroum 2000). This fact reinforces the concept that diverse groups have been shown to be more effective at producing results; if engineers wish to succeed they must be ready to perform within the context of this fact.

An International Solution

With this identified need for globally competent engineers has come avid discussion on what is the best method for introducing students to this context and providing them with experience that can aid in their careers. Experiential learning theory proposes that lived experience is the most effective and enduring route for memory and learning (Jurgens & McAuliffe, 2004). Most current efforts to prepare a globally competent workforce have been directed toward undergraduate education through international study abroad programs offered by several American universities (Institute of International Education, 2004.b) and NSF-sponsored international Research Experiences for Undergraduates (NSF, 2001).

Studying abroad is one of the few options that can provide experiential learning in an international setting, and has thus become a center-point in discussions (McHargue and Baum 2005), (Nasr, et al. 2002), (Hirleman, Groll and Atkinson 2007). Despite this fact and the knowledge that the engineering field is an international one, the participation of engineering students in study abroad programs is dismally low; roughly less than 3 percent (Marcum 2001). While there has been a recent rise in the popularity of study abroad programs in general, engineering students have not participated in this trend and are severely under-represented (Berkey 2010), (Institute of International Education 2010), (King and Young 1994). This low turnout must be addressed, as it has been shown that study abroad experiences leave a lasting impact on participants that influence their personal and professional life for years to come (Armstrong 1984).

There are a variety of reasons that prevent typical engineering students from participating in study abroad programs. Incorporating international experience into the typically highly regimented engineering curricula has proven to be a challenge that cannot always be met by typical study abroad programs (Lohmann, Rollins and Hoey 2006). Typical programs span a semester or year period, which almost never meshes well with a curriculum that squeezes as many major relevant courses into four years as possible. It is a common fear that studying abroad will lengthen the time required to graduate. Affordability, diversity of program, and capacity, and transfer of credits are acknowledged to be key issues when students are deciding to take a study abroad course (Marcum 2001), (Parkinson 2007). To address the limitations of conventional study abroad programs, short-term courses have been put forth as an option that can fit within a rigorous course load.

Short-term international courses provide many opportunities that traditional study abroad courses cannot. One such opportunity is that courses can cater to focus areas of students while ensuring that proper credit will be received for participation. This implies that the international experience gained will be directly relevant to the students' interests and most likely their career path. Due to the short nature of the course, associated costs are likely to be less than semester or year-long study abroad programs. It has been shown that short-term non-language based study abroad programs can improve participants intercultural sensitivity, implying they will be better

prepared for an international engineering workplace (Anderson, et al. 2006). The IPWRM course is one such program that provides an international experience that is relevant to participants' field of study while having a duration that is approachable and will not impair graduation timelines.

Global competence should include an understanding of the relevance of international cultures to a student's major (Lohmann, Rollins and Hoey 2006). The IPWRM course provides this relevant experience while taking advantage of best practices that help to ensure the success of the course. Due to the fact that the course is departmental, it takes advantage of the fact that departmental study abroad programs serve to both speed the process for incorporating international topics into an institutions curriculum and to help students gave an international professional perspective through linkages between host and home curricula (Praetzel, Curcio and Dilorenzo n.d.). Additional features of the course that have been identified to increase the success of a program are involving several faculty members in a program, preparing students before departure, taking advantage of already existing university infrastructure, and a college leadership that has made a long term commitment to the program (Parkinson 2007). The course provides the now necessary international experience and exposure to multiculturalism while overcoming the barriers of traditional study abroad programs. The predominant goal of the IPWRM course is to provide students with a unique experience that will aid in preparing them for the global engineering workplace.

4 A Unique classroom: The Netherlands – United Kingdom 2010

A diverse group composed of 14 students ranging from undergraduate studies to PhD candidates took the plane to Europe during the summer of 2010. They were accompanied by two University of Iowa faculty members. This time, the IP class took the students to The Netherlands and the United Kingdom from May 17th, 2010 through May 31st, 2010. The class was organized by The University of Iowa in cooperation with UNESCO's-Institute of Water Education (UNESCO-IHE), University of Bristol, Cardiff University and Imperial College of London.

Before leaving the US, Several educational sessions were organized at the Iowa Institute of Hydraulic Research (IIHR) to discuss the logistics, available funding, cultural differences, and to assign projects to students. A pre-survey and post-survey were completed respectively before and after the study abroad class by 14 students and 2 faculty. The main topic of the course -Living in floods" followed up the efforts of the Iowa Flood Center to respond to the urgency of cutting-edge research and education to address flooding in Eastern Iowa. Therefore, several students who attended this course came from this center and were eager to learn the techniques used by the Dutch and the British to overcome flooding over centuries.

Indeed, the host-countries for the IP class are unique in water-related fields. They experienced severe floods in the past. For instance, in 1953 a colossal deluge hit The Netherlands. Over 2000 people died and 150,000 hectares of land were inundated (Deltawerken 2004). On the other hand, the United Kingdom has also an historical record of important

inundations. In order to protect their lands and people, the Dutch and British developed sophisticated flood control system and high-technology models to predict and monitor flooding. They are well-known for unique flood mitigations projects.

The first stop was in The Netherlands, a country that is home to the delta of three major rivers and where more than 50% of the population is living below sea-level. Most of the students travelled the weekend preceding the official start date of the course to experience the exclusive Holland tulips festival and to do sightseeing. Figure 4-1 illustrates the means of transportation, the itinerary, and the class schedule. University of Iowa Students and Faculty spent about a week in Delft, a city located South Holland. They had a first-hand experience of the Dutch flood technology and culture by being exposed to state-of-the-art techniques, visiting research facilities and hydraulic structures, meeting colleagues and peers, networking, and melting into the local population. Detailed guided tours were given in Belgium (Sigma River Project) and The Netherlands (Deltaworks). The stop to Belgium was brief but intense. It included a visit to the Flanders Hydraulic Research (Waterbouwkundig Laboratorium). This institute focuses on hydraulic, nautical research, and water management and it advises the Flemish government on water related projects. Following research facilities, the Sigma Plan was presented to the students. This project followed the storm surge that flooded Northern Belgium in 1976. The plan was actualized in 2005 and included a combination of strengthened dikes and flood control areas (Peeters 2010). The speaker showed that today the Sigma Plan flood protection project also encompasses ecological needs and addresses environmental issues due to the implementation of the project. The pilot project in Lippenbroek was highlighted by the speaker. Lippenbroek is a polder used as a Flood Control Area and intertidal habitat restoration. A boat ride along the Scheldt River allowed the group to see the dikes and to visit a flood control area. The day terminated in a visit of the city of Antwerp. Many of us enjoyed culinary delicacies such as pralines and Belgian fries.

Another important visit was the Deltaworks, which were built between 1950 and 1997. The Deltaworks contained a state-of-the-art set of gates, dikes, sluices, locks, and storm barriers. These structures protect over millions of people living in the South Western part of The Netherlands. The visit consisted of field trips at the Eastern Scheldt Storm surge barrier and the Maeslant storm barrier. The former is a barrier composed of movable components, which will be closed in case of surge storm. It is the biggest hydraulic structures in the world. The latter consisted of two gates which can swing. Those movable gates protect the Rotterdam population estimated at 1M people from being flooded during storm surge. This is one of the largest moving structures on earth. The deltaworks project is listed as part of the Seven Wonders of the 20th century (ASCE 1994) **Figure 4-2** illustrates the Sigma River and Deltaworks visits. Dutch guides enthusiastically shared knowledge about techniques used to implement those projects and history behind the motivation. Students learned about the planning, design, operation, and maintenance of these enormous structures.

Remarkable exchanges were made between IP and Dutch groups via visit of the leading research institute in water, soil, and subsurface –Deltares". In a very welcoming setting Professor

Arthur Mynett introduced Deltares, presented the concept of environmental hydro informatics and the numerical models used to address water related and environmental issues. Flood center students shared their knowledge, and experience about projects conducted on the Mississippi River. Professor Allen Bradley from the University of Iowa group gave a presentation about the IFC. Later, the group visited prototypes, models, large-scale wave facilities (e.g. Vinge Basin). The last two days in Delft were shared between TU-Deflt and UNESCO-IHE: an institute specialized in water education. Civil engineering professors presented their research and challenges faced while implementing water-related projects. -Room for the River", a national program by the Dutch government to increase safety for its nation and environmental quality of its river basin, was presented. The lands along the rivers are protected by dikes, which height had increased over years, the lands which are dropping behind the dikes are more and more exploited by the population, and limited space is available for the rivers. (Hoekstra 2010). The speaker presented the techniques employed to address this issue. For instance, some actions imply lowering of the floodplains, removing of hydraulic structures, and getting rid of some manmade dikes. Among the challenges associated with the implementation of the program are the reallocation of families and farms, and the amendment of existing regulations. The program costs about €2.2 billion to the Dutch Government. Those lectures were an ideal occasion for U IOWA students to interact with Dutch faculty, and discuss about flood modeling tools (e.g. Delft 3D), flood management and protection techniques, environmental issues and ecological problems associated to those constructions. From May 17th to May 20th, students attended intense workshops, visited unique research facilities inaccessible to general public, and had valuable networking with Dutch peers.

Other non-academic activities were possible. The US group assisted to local fair in Delft that looks like a state fair in Iowa. Typical Dutch products could be tasted especially cheese and exotic fruits from Asia. Students have detected similarities between Iowa City and Delft. Both towns are small and they are both college towns. Differences were also noticed. Biking is a main transportation in Delft. This is not surprising. The Netherlands are well-known for their well-developed biking infrastructures. If in Iowa City some bike, in Delft most of the students used their bike as their primary transportation. A striking difference with the US College Town is the high-cost of living in Delft. Dutch students reported that eating out is not a common habit for students and it was too expensive for them. Iowa and Dutch students agreed.

The cultural aspect of the class was not negligible. The weekend of May 21st, students visited the lively city of –Amsterdam". The IP group had a tour of the city by taking a boat ride along the canal. Students soaked up in the city atmosphere and had a unique experience ranging from jazz cafe to rock concert. A two-day pass permitted to discover the city architecture, to visit the museums, and to interact with Dutch people in a non-academic setting. Overall, Amsterdam is a busy city with several attractions, diverse cuisine, and a unique atmosphere.

On May 23rd, the tired but motivated IP group took the plane from Amsterdam to Bristol located South West England. Faculty and students settled at Burwalls situated at the edge of Clifton village offering a charming view of the city of Bristol. Right of the housing is situated the

attractive Clifton Suspension Bridge (See Figure **4-3** a.-). Students were pleased by the stunning views from the bridge. The next day the course instructor conversed about the logistics of the second part of this study abroad class. Expected assignments were discussed and updated based on the current situation of the IP Class. From May 24th to May 28th, U Iowa Group, British Students and Faculty travelled across the UK to visit universities (University of Bristol and Cardiff University), research facilities (HR Wallingford, Halcrow), and governmental agencies (EA at Wales and Tewksbury).

Students and faculty from the Department of Civil Engineering at the University of Bristol presented their research work and projects. Dr Han, a reader in Water Engineering, presented the main research focus of the department. The on-going project AQUATEST, which goal is to develop a low-cost device to water testing in the developing world, was presented. Presentations were made on hydro informatics, rainfall forecasting, hydrologic modeling, remote sensing, GIS and flood estimation as well as d non-structural flood mitigation. For example, Liguori (2010) assessed hybrid models for rainfall forecasting by coupling Numerical Weather Prediction (NWP) models and radar nowcasts, while Liu (2010) outlined the criteria to choose the best set of data when calibrating flood furcating models. Ishak and Han (2010) used sensitivity analysis to report the most important weather variables to estimate evapotranspiration using NWP models. A large range of numerical models were presented. Most are meant to predict flood in urban areas. U Iowa students had also the opportunity to meet and to assist to workshops organized by the School of Geographical Sciences under the direction of Professor Paul Bates. Projects using modified version of LISFLOOD, a grid-based and spatially distributed model used to simulate floods in large river basin in Europe. University of Iowa highlighted the main important projects conducted at the Iowa Flood Center. Challenges and future research of the IFC were discussed.

IP took students to Wales, an interesting country situated west of England, to visit Cardiff University and to attend presentations organized by the Hydro-Environmental Research Centre group. Professor Roger Falconer presented hydro-environmental assessment studies in the Severn Barrage. Dr William Rauen gave a talk on contaminant transport processes using flume experiments and a 3D-Hydrodynamics model (ECOMSED). Dr Lin gave a tour of the hydraulic laboratory where students could see a large tidal basin, recirculating flumes, and a large tidal flume used to acquire field data. The detailed Severn Estuary and Bristol Channel physical model was also shown (See Figure 4-3 b.-). The model has the following scaling: $\lambda_{xy} = 1:25,000$ and $\lambda_z = 1:125$

After lunch, Professor Falconer gave students a quick tour of Cardiff. The rest of the stay in Bristol was shared between workshops at Environmental Agencies (EA at Wales and Tewksbury) and two-world leading companies specialized in water-related fields, HR Wallingford and Halcrow. The two are independent research and consultancies companies specialized in civil engineering and environmental hydraulics. They provide assistance and advice to the British government, international organizations, and partner with University research lab. At the Environmental Agencies, officials presented techniques and tools for flood risk managements. They made demonstrations of the forecasting & warning system used in England and Wales. Climate change is a challenge for the British government that is not neglected in flood modeling studies. Officials at the EA – Wales reported that the rivers flow peaks are 20% higher and the sea-level is expected to be 1m higher by 2110. A detailed review of the Tewkesbury Town flood in 2007 was presented and students assisted to a demonstration of erection of demountable and temporary flood defenses. Figure **4-3** c) and d) illustrate respectively the flood defense and the water elevation during historical floods in Tewkesbury town. At Wallingford students learned about the Life Safety Model (LSM2D) used for evacuation and reallocation planning. Halcrow presented the model ISIS used for river modelling studies just like Mike 11 and HECRAS. The model is used for flood risk mapping, flood forecasting, flood incident management and emergency planning.. ISIS 2D is now available for 2D flood modelling. During those presentations, students learned about models available for flood risk mapping and managements.

IP Students left Bristol in the morning of May 28th for a new set of presentation in London. In a friendly atmosphere, Professor Čedo Maksimović and students welcome the University of Iowa group to London Imperial College. Presentations were very diverse. The Imperial Students presented projects focusing on urban flood mapping, flood regulations, disaster prediction and management, and rainfall forecasting. Two IFC students presented about their work at the research institute. For example, PhD Student Luciana Cunha talked about the hydrological model CUENCAS. Two studies cases (Cedar rapids 2008 flood in Iowa and City of Charlotte in North Carolina) were showed. The former is to study the effects of basin scale on flood prediction and the latter is to study the effects of land cover changes on flood risk intensity. London Imperial College group, University of Iowa students and faculty gathered in a cheering reception organized by the Imperial group. The IP Group developed links with colleagues and faculty for long-time friendship and further collaboration. University of Iowa group provided thanking gifts to the Imperial College group. This was done after each visit.

The rest of the stay was in a more relaxing setting. Students were provided a two-day pass to visit museums and historical structures in London (e.g. London Bridge, Big Ben, etc.). The group took a boat ride to the famous Thames Barrier, which is the second largest movable flood barrier in the World. Students were pleased by the stunning view of the London Bridge which is a breathtaking civil engineering structure. University of Iowa students noticed the easy accessibility of public transportation in London. Students in London do not need a car to travel far. The Metro system is very efficient and they can easily travel across the UK. Some reported the air pollution in this busy city compare to Iowa City. Nevertheless most had a great experience meeting students from the London Imperial College with whom they continued to hang out over the weekend.

The class terminated on May 30th. Some student travelled to the US while others stayed longer in Europe for a well-deserved vacation after a very intense and unique study-abroad class.



Figure 4-1: Itinerary of the IP Class in Europe 2010



Figure 4-2: Visiting the Sigma River Project (Belgium) and the Delta-plan (The Netherlands)



Figure 4-3: Visiting Bristol and Wales

Date	Day	A.M.	P.M.	Accomodations*	Host			
	of the Week							
The Netherlands								
15-May-10	Saturday	Arrival		Delft				
16-May-10	Sunday	Arrival	Flower Exhibition	Delft				
17-May-10	Monday	Course opening & logistics	Delft Tour	Delft				
18-May-10	Tuesday	DELTARES	TU Delft	Delft				
19-May-10	Wednesday	Sigma River Project (Belgium)		Delft				
20-May-10	Thursday	Deltaworks Coastal Flood Defense System		Delft	I. Popescu			
21-May-10	Friday	UNESCO-IHE		Delft	I. Popescu			
22-May-10	Saturday	Amsterdam Sightseing Tour (Canal Tour, Museums)		Amsterdam				
23-May-10	Sunday	Trave	el to UK					
		Unit	ed Kingdom					
23-May-10	Sunday		Arrival from NL	Bristol				
24-May-10	Monday	Course logisics	Bristol University	Bristol	P. Bates			
25-May-10	Tuesday	Cardiff University	EA Wales	Bristol	R. Falconer			
26-May-10	Wednesday	HR Wallingfrod	Halcrow	Bristol	R. Falconer			
27-May-10	Thursday	Flood Project (??)	Flood Project (Severn Valley & S. Wales)	Bristol	P. Bates			
28-May-10	Friday	Travel to London	Imperial College	London	C. Maksimovic			
29-May-10	Saturday	Boat River Tour (& Thames Barrier)		London				
30-May-10	Sunday	London Sightseing Tour		London				
31-May-10	Monday	Departure for USA						
Delft	DUWO, Mina Krusemanstraat UNESCO-IHE Housing Complex (http://www.duwo.nl/eCache/DEF/8/945.html)							
Amsterdam	Lloyd Hotel & Cultural Embassy (http://www.lloydhotel.com/)							
Bristol	Bristol Housing Burwalls Center (http://www.bristol.ac.uk/burwalls)							
London	Cranley Gardens Hotel (http://www.cranleygardenshotel.com)							

Table 4-1: Detailed of the IP Class agenda

5 Results of Survey

Participants in the 2010 IP course completed pre- and post-trip surveys covering the same questions as the 2008 survey. The 2010 participants had more travel experience than those who made the trip to Egypt. Only two had never traveled abroad prior to the course and four more had spent less than one month overseas. Over half the participants had extensive international travel experience, most having lived abroad in some capacity. Six of the participants had prior travel experience in Europe, a number that contrasts sharply with the Egypt course, when only one student had previous travel experience in the region.

The results of the surveys for the 2010 program in the Netherlands and the United Kingdom were similar in many respects to those of the Egypt course in 2008. Using the same statistical measure, t-Tests with a 95% confidence interval, eleven of the questions yielded statistically significant differences – five more categories than in 2008. Several of these significant differences overlapped with the observations from the Egypt trip. Students again reported strong gains in knowledge of the culture, society and water resources management issues of the destination countries. The surveys also show that student concerns about language barriers, personal security and committing a cultural faux pas decreased significantly both times.

Additional areas where students reported decreased concern after the Europe trip were illness, money and gender roles. None of these areas saw significant change following the Egypt trip. In the case of the illness question, the students on the Egypt trip actually reported a higher level of concern after the trip (though not statistically significant). Money was ranked as a less-important issue after both trips, although the change was not significant in the case of the Egypt course. The fact that money was considered such an unimportant problem for students in 2010 may have been aided by the sharp decline of the Euro in the months preceding the trip.

The qualitative answers given by students on the 2010 surveys reflect those of the 2008 surveys. When asked if students would pursue another IP opportunity in the future, all but one answered yes and several provided illuminating responses. Examples include:

- It was an extremely valuable and enjoyable experience
- It was a unique experience. I built some great memories and... I will surely recommend it to others
- ...(it is the) only chance to travel abroad affordably

Another component that students highlighted repeatedly was the value of interacting with international peers and colleagues. Some reactions:

- Glad to meet people in my field
- ...time with international peers and colleagues was enjoyable

• The two social outings, especially the one in London, were crucial for making contacts

The emphasis students place on these interactions was reinforced by the fact that lack of time or opportunity to interact with international peers was one of the few common critiques provided in response to open-ended questions about how to improve the course.

The most important observation to take away from these surveys is that, in the opinion of the participants, these courses produce several important results. Students in both courses overwhelmingly reported significant gains in their understanding of water resources management issues in the countries visited. Moreover, they also indicated greater knowledge of society in those countries. This benefit, extending beyond the specific content of the course, is particularly relevant in this era of globalization.

Besides increasing understanding of society in the host country, the courses also tangibly improved students' level of comfort traveling abroad. The fact that post-trip survey results from both courses showed students were significantly less concerned about language barriers, personal security and cultural faux pas afterwards supports this conclusion. Given these responses it is no surprise that both surveys showed students to be more comfortable traveling abroad after the course, whether to the host country or any other international destination.

6 Conclusion

Over the course of the previous decade the IIHR – Hydroscience and Engineering institute has provided an opportunity for engineering students to participate in a study abroad experience that would be otherwise impossible. The rigors of the highly demanding engineering curriculum have been circumvented by the application of a short-term model that attempts to address the obstacles to studying abroad. The two week excursion to the Netherlands and the United Kingdom presents a case study that showcases the exposure to concepts present in differing academic and professional cultures. The wide variety of lectures, presentations, and field trips are provided in a context of cultural exposure that serves to acclimate students to a career that is increasingly likely to be multicultural and global. Surveys that were completed both before and after the Netherlands/UK offering of the course, in conjunction with surveys from a previous course to Egypt, provide quantitative evidence towards the benefits of the short-term model. Qualitative and quantitative results from the surveys also illustrate the parallel gains in technical and cultural knowledge that only a course such as IPWRM can offer. Evidence points toward the fact that the IPWRM form of the short-term study abroad model prepares students for increasingly global environment of the engineering workplace, and the model must be developed further and find more wide-spread implementation.

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INTERNATIONAL PERSPECTIVES IN WATER SCIENCE AND MANAGEMENT

LIVING WITH FLOODS

Living with floods: Effects of land-cover changes on flood risk

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Summer 2010 July 30, 2010

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1 Abstract

Flooding is one of the natural disasters that cause major human fatalities, cultural and environmental damages and economic losses. With the intense modification of land-use, alteration and urbanization of floodplains, and possible more frequent extreme rainfall events as a consequence of global climate change, floods can become more frequent, more devastating and more extreme than in the past. In this context, it is imperative to develop an understanding of the relationships between land-use change and flooding. However, the extent of the information and tools required to determine these relationships at a large scale are complex and more work in the area needs to be done.

Due to their geographical location and landscape, the UK, the Netherlands and Belgium have a history of large flooding events and are pioneers on research on flood modeling and flood risk management. With the goal of learning from their experience, the International Perspectives in Water Science and Management course spent two weeks visiting institutions in these countries. This paper summarizes the lessons learned during this course.

2 Introduction

Floods are destructive and strongly affect people lives. The International Disaster Database recorded an increase in the number of floods events in Europe in the last decade, and attributed that to direct effects of human interventions in river basins (e.g., floodplain destruction and occupation) together with the indirect consequences of global warming.

Floods are natural phenomena which cannot be prevented. However, human activity is contributing to an increase in the likelihood and adverse impacts of extreme flood events. The scale and frequency of floods are likely to change due to climate and land cover change. Even though the consequences of these changes are still not well known, it is expected that rainfall will become more intense, and sea levels will rise in some regions of the globe. These effects combined with inappropriate river and land management, and construction in flood plains, are expected to change flood patterns, and events that cannot be predicted from the past are likely to occur. The changes in the likelihood of extreme disasters constitute a potential threat to human life, economic assets and the environment.

The main difficulty in assessing the hydrological and hydraulic effects of changes is the reliance of traditional models on long series of hydrological and meteorological data. These models basically look at the past to predict the future, under the assumption that physical processes are stationary. This assumption is violated under land cover and climate change. In this case, the past does not represent the future, and the only way to predict the future is to rely on the understanding of the physics behind flood generation. In this paper we present an overview of methods used for hydrological and hydraulic prediction of floods. We discuss the main weakness of the traditional models and present what we believe to be a better approach to model floods.

Flood predictions are essential for the design of optimal flood risk management projects. The development of flood management projects is a multidisciplinary task that requires a large amount of information. Hydrological, hydraulic and flood damage models, as well as decision support systems, are some of the instruments used to generate the required information. The final project goal is to decrease the consequences of floods through the adoption of structural and non-structural flood mitigation measures. For many years the flood mitigation approaches have focused on reducing the probabilities of floods though the implementation of structural measures (e.g., dams, rive channel modifications, and dikes). These measures are designed to provide protection up to certain flood intensity (return period). Even though effective, these measures are usually very costly, and do not provide protection to very rare events that are the ones that cause the most destruction. Current trends consider that floods are natural phenomena that cannot be prevented, and measures should be taken to decrease the impacts of living with them. The new directives in terms of mitigating the consequences of floods will also be discussed in this paper.

This paper is the results of the authors' participation on the International Perspective in Water Science and Management provided by IIHR in 2010. For the first time this course, offered by The University of Iowa every other year, had a specific theme that was "Living with Floods". During the course, participants had the opportunity of visiting countries that are facing these problems for centuries, like Netherlands, Belgium, England and Wales. Their experience dealing with floods acquired during many years was shared with the course participants through the contact with universities, governmental agencies and consulting company located in the visited countries. The learning that was achieved during the two week course could not be achieved through a traditional class system, where students and professors interact in the confined space of a classroom. The authors of this paper are glad to have had the opportunity of participating in this insightful and priceless experience. This paper concludes with a description of strategies and programs that are in place in the Netherlands, Belgium and the UK.

3 Flood probability, vulnerability and risk: the base for flood risk management

Floods can be defined as water outside its normal confines that is temporary covering land (FLOODsite-Consortium 2005). Floods are usually natural phenomena that can be characterized as a threat, depending on the area they occur and the damage they cause. They happen at all scales and can be classified according to the cause of the event, being the main types flash floods, summer and winter convectional storm induced floods, snow-melt floods, sea surge and tidal floods, rising ground water floods, and urban sewer floods (Schanze 2006). **Flood probabilities** are estimated by flood-frequency studies that attempt to calculate the peak flow's magnitude (intensity) associated with a certain exceedance probability (frequency) or recurrence interval for specific locations in a river.

Vulnerability describes inherent characteristics of a system that create the potential for harm but are independent of the probabilistic risk of the occurrence of any particular hazard or extreme event (Sarewitz et al. 2003). Susceptibility and societal values (FLOODsite-Consortium 2005) constitute the basis for the estimation of vulnerability, which is expressed by direct and indirect effects which can be tangible or intangible (Meyer and Messner 2005). Societal values are independent from the hazard, while susceptibility indicates the process of damage generation and depends on the type of flood event and the constitution of the elements at risk.

Flood hazard is the probability of the occurrence of potentially damaging flood events (Sarewitz et al. 2003). The real materialization of the damage when the hazard exists depends on the vulnerability of the exposed elements. Considering the previous definitions, **flood risk** is the product of flood probability by the expected potential damage (function of vulnerability). The expected annual damage is calculated by the integral of the risk density curve.

Risks are non-zero and cannot be made zero, but both floods probability and expected damage can be minimized through risk management projects. Flood risk management is a systematic action in operating, planning and design a flood mitigation system. The steps of risk management may be summarized as (Ale 2002; Plate 2002): (1) Risk analysis, (2) Risk assessment, (3) Risk reduction (acceptance), and (4) Control. Figure 1 presents an overview

of the flood management processes. Risk reduction and control involve coordinated and economical investment of resources to minimize, monitor, and control the probability or impact of unfortunate events (Hubbard 2009). Some of the activities that should be contemplated by flood risk management projects are prevention, protection, preparedness, emergency response, and recovery from floods.

As demonstrated by the figure, risk analysis and assessment forms the basis of these projects, affecting any action for flood mitigation (Plate 2002). Risk analysis attempts to systematically characterize and quantify risks, through the hydrologic estimation of flood discharges and the delineation of flood maps through hydraulic methods based on flood depths and flow velocities. Risk assessment presents an overall evaluation of risks based on the results of the former analysis, judging risks as acceptable or not from an individual or a societal viewpoint. Massive data requirements, high cost, and large uncertainties due to incomplete representation of the natural system, or the use of inadequate oversimplified methodologies, are some of the challenges of the flood management process. These aspects will be discussed in following sections of this paper.



Figure 1. Flood Management Process

4 Modeling land-cover effects on flood risk

As previously discussed, the impact of floods can be reduced through holistic flood risk management projects. Risk assessment is at the core of such projects, as it delineates the decision making process (Ale 2002; Plate 2002). Risk assessment projects involve (1) hydrological, (2) hydraulic, and (3) socio-economical studies, and they usually require a large amount of data. In this section, we briefly discuss some methodologies traditionally used in risk assessment, and their main limitations.

4.1 *Flood frequency*

The first step of any flood risk management project is a hydrological study that attempts to obtain the relationship between peak discharges (PD) and their exceedance probability, also called return period. Three different methodologies that are commonly used are as follows: (1) Statistical methods attempt to fit extreme probability distributions to directly measured annual PD; (2) Calibration-based hydrological models apply equations that are typically derived for punctual processes, assuming that "effective parameters" can be obtained for large areas. Since these parameters are not directly measurable in nature, their values are obtained through calibration procedures; and (3) Regional regression equations estimate peak flows as a function of a basin's characteristics, usually using the drainage area. The parameters of the regressions are statistically derived using stream flow data from large areas without any link with the physical processes that produce floods. All methodologies strongly rely on the availability of long series of historical hydro-meteorological data. The first two methodologies require data specifically for the study area, while the third method extrapolates available information from similar watersheds.

In the literature many alternative statistical approaches have been proposed for modeling annual maximum PD under non-stationary conditions through parametric representations of the time-varying mean and variance of the annual flood peak distribution (Coles 2001; Cunderlik and Burn 2003; Katz et al. 2002; Khaliq et al. 2006; Leclerc and Ouarda 2007; Strupczewski et al. 2001). These methodologies attempt to extract from time series floods with different return periods and non-stationarities on mean and variance of the annual flood peak distribution. These methods require very long series of historical data, since floods with return periods of more than 500 years are extrapolated from it. Very short time series can also provide uncertain estimation of non-stationarities, since dry-wet climate cycle can have periods that last more than centuries (Yu and Ito 2003).

Calibration-base hydrological models have also been used to estimate the effects of land-cover changes on floods (Legesse et al. 2003; Li et al. 2007; Moriasi et al. 2007; Santhi et al. 2001; Tripathi et al. 2005). The Soil and Water Assessment Tool (SWAT) is one of the most applied models since it takes advantage of the Soil Conservation Number - Curve Number (SCS-CN) method that provides a direct link between land surface properties and runoff generation process (Abbaspour et al. 2007). SWAT divides the watershed into hydrologic response units (HRUs) according to the user specification and the response of each HRU in terms of water, sediment, nutrient, and pesticide transformations are determined individually, and then aggregated at the sub-basin level' (Arnold et al. 1998). This is one of the main criticisms of SWAT model, since the user defines the scale of each HRU, varying from small hillslopes to entire watersheds. The main problem with this concept is that many of the equations applied by SWAT (e.g., SCS-CN) were derived in a hillslope level and should not be applied to very large areas. To overcome the uncertainties due to these simplifications, parameter calibration is necessary, where the modeler optimizes the result for the outlet of the basin. A good hydrograph fitting at the outlet of the basin does not guarantee that processes are being correctly representing throughout the basin, since one process can be compensating the fails in representing other processes. Ghaffari et al. (2010) in an application of SWAT model to simulate the impact of land-use change in an Iranian Basin identified 17 significant parameters that require calibration. It is clear that many uncertainties are involved in calibrating 17 parameters for 63 sub-basins using streamflow data at the outlet of the study area.

Simpler models that attempt to represent the dominant processes responsible for floods could provide results more representative of the natural system across different scales. As an example, CUENCAS, a hillslope-base distributed model, has been developed with this goal (Mantilla and Gupta 2005). Based on the shape of the terrain as given by the digital elevation model (DEM) data, CUENCAS compartmentalizes the landscape in small areas where runoff generation occurs (hillslopes with area on the order of $0.05 - 0.1 \text{ km}^2$). These areas are naturally connected by the river network (links with length on the order of 0.1-0.5 km). Physical equations are written to simulate physical processes at the scales that they occur. Mass and momentum balance equations are used to solve the physics of rainfall-runoff transformation processes and the transport of water through the river network. The Soil

Conservation Service Curve Number Method (SCS-CN) is used to simulate rainfall-runoff transformation at the hillslope scale. Calibration is avoided, since model parameters are directly related to observable catchment and river network characteristics. Parameter estimation is based on field measurement data and remote sensing information widely available on a nearly global base. This model conceptualization explicitly considers land surface spatial variability and provides PD information for each channel-link in the river network. These are essential data for a multi-scale assessment of flood risk.

The third method largely used in US is the estimation of regional regression equations. This method takes advantage of the scale relationship between peak flow and drainage area. The parameters of the regressions are statistically derived using stream flow data from large areas. This method is valid if a link between the physical processes that produce floods and the parameter of the scaling relationship can be established. To establish this link long datasets of historical data for regions with different climatology, topography and ecology are required, but are not available. These links can also be established through the use of hydrological models that correctly represent the physics of floods across scales, without requiring calibration.

One of the biggest challenges towards flood mitigation efforts are the uncertainties involved in the quantification of the main model parameters. The uncertainties are even higher when non-stationarities due to land-cover and climate change exist.

4.2 Inundation map

The second step of risk assessment analysis involves the delineation of inundation maps for different return periods using hydraulic models. Many methodologies are available and vary in terms of complexity and data requirements. A comprehensive review of methodologies currently in use and their associated uncertainties is presented in NRC (2009). In general, more complex hydraulic models (from 1D to 3D) present larger data requirements and higher costs of implementation. The main input information for any of these models are PD provided by hydrological studies. The extent of the floodplain region is estimated by the propagation of the PD punctual information through long distances in the river network, usually under the assumption of steady state flow conditions. As commonly used hydrological methods only provide PD information for a few (gauged) points in the river network, very complex hydraulic models must be applied, requiring a detailed description of channel geometry and roughness, high resolution DEMs and observed values of water depth and flow velocity for model calibration. Information with the resolution and accuracy required for these models is very costly and not usually available. Furthermore, the application of complex models in the absence of the appropriate dataset does not yield accurate results (Horritt et al. 2007; Marks and Bates 2000).

According to some studies, in the proximity of points for which the prediction of peak water discharge is available, a simple model that approximates the flood wave with a series of planes produces accurate results (Bales and Wagner 2009; Bates and De Roo 2000; Horritt et al. 2007; Hsu et al. 2003; Merwade et al. 2008; Overton 2005). Having hydrological models that are able to provide high spatial resolution peak flow information throughout the river network can decrease the cost and simplify the process of generating inundation maps.

4.3 Flood damage

Inundation maps are combined with social and economic spatial data to accomplish the last phase of risk assessment projects that correspond to the estimation of potential flood damages. Flood losses can be classified as direct (losses that result from direct contact with flood water, e.g. buildings) or indirect (e.g. transport disruption), and tangible (losses that have a monetary value, e.g. infrastructure) or intangible (lives and injuries). A comprehensive economic assessment of losses involves a large number of parameters, some highly subjective, that interact in a complex and non-linear manner (Murlidharan et al. 1997). Some of the negative effects of floods that should be accounted for are: death, property loss, cumulative increase in personal and national debt, increased incidence of certain diseases, soil erosion, sand casting, penetration of saltwater into soils and aquifers, siltation of rivers and irrigation canals, and damage to and the destruction of public infrastructure, roads, railway beds and other transportation infrastructure (Cuny 1991).

In a study to identify the main uncertainties of flood mapping, the NRC (2009) concluded that even in locations with a long archive of stream flow measurements, floods cannot be accurately estimated. Non-stationarities caused by land-cover or climate change (and patterns) add yet more complexity to the already complicated flood phenomenon since
present and future land surface and climate configurations are not reflected in past hydrological observations.

5 Effects of land-cover on flood risk: the need for a multi-scaling approach

Earth's surface is constantly modified by natural or human induced phenomena. Volcanic eruptions, earthquakes, hurricanes, wildfires, landslides, massive animal migrations are example of natural land-cover change, while humans constantly transform natural habitats into agricultural areas, urban areas, or extract natural resources (vegetation, minerals, water, etc).

Land-cover changes can modify the flood hazard and vulnerability of an area. As an example, it is possible to describe the flood hazard and vulnerability created by a flood event with the same intensity in a floodplain area previously occupied by forest and transformed to urban area. The same PD in the forest environment may not present any flood hazard or vulnerability, but might present high flood hazard especially in areas closer to the river, and the level of vulnerability will depend on socio-economic aspects and the level of preparedness of the affected area.

Land-cover changes also affect the partitioning of rainfall into the different components of the hydrological cycle, causing changes on flood generation processes. The hydrological effects of land-cover change will depend on the type and scale of the land-use change. The most relevant changes in terms of occurrence frequency and level of interference in floods are: agriculture intensification, urban development, transport development, and deforestation. Agriculture intensification was usually achieved by draining floodplains, removal of natural vegetation cover, compaction of the soil by farm machinery, and homogenization of the landscape. Urbanization implies filling and loss of floodplains, smoothness and loss of infiltration capacity of the soil. Urbanization has also caused the modification and straightening of streams, reducing their water and sediment carrying capacity and decreasing the traveling time to receiving waters downstream. To minimize costs, roads and railways are usually constructed in river valleys, incentivizing the development of small communities in these areas. Another way how travel development can increase flooding probabilities is the installation of narrow culverts that create a dam effect in certain areas. Deforestation results in loss of vegetative cover, changing the structure of the soil and minimizing the water retention capacity of the area. All these factors contribute to changes on flood frequency and intensity around the world.

The local effects of land-cover changes on flood probability have been already intensively studied and quantified. Flood intensity increases as the result of an increase on runoff generation or a decrease on the basin concentration time. Modifications on rainfall-runoff processes are usually the result of changes on the soil infiltration and retention capacity. The concentration time of the basin changes when the land surface becomes smoother and the resistance to the flow decreases. One example of this type of situation is the urbanization process that has been proved to have a large impact on flood hydrology by increasing surface runoff and decreasing infiltration (Leopold 1968; Sauer et al. 1983; Smith et al. 2002). Another process that can reduce infiltration drastically is fire. Luce (2005)found that fire, depending on its intensity and duration, can decrease the capillarity of soils or create soil crusts, decreasing the infiltration capacity of soils and increasing runoff. Agricultural practices that increase soil erosion and decrease infiltration also are responsible for the increase on runoff at the local scale.

The opposite effect can also be observed at the local scale; some land-cover changes can reduce runoff or slow down the flow over the landscape. In this case a reduction on flood intensity at the local scale can be observed. For instance, there are several Best Management Practices (BMPs) that have been developed to restore infiltration and reduce overland runoff in agricultural and urban landscapes. Also reforesting an area or restoring it to prairies after being used for agriculture is expected to increase infiltration, although it might take several years to observe this effects until vegetation is completely established (Asbjornsen et al. 2007; O'Connell et al. 2007).

Most studies have investigated the relationship between land-cover, and/or land management and runoff generation at small spatial scales. The difficulty resides in extrapolating these local effects to larger scales. Larger scales studies require more complex models that include a multi-scale representation of the natural system. The link between runoff generated at a local scale and peak flow at larger scales is complex and non-linear, since the dominant processes that control hydrological processes change across scales. For smaller scales the rainfall-runoff transformation plays an important role, determining flood probabilities. As the scales increase the river network properties and water flow processes dominate the response of the basin (Gupta and Waymire 1990; Sivakumar 2005).

The Flood Risk Management Research Consortium (FRMRC) of the UK, gathered extensive field data and developed a multidimensional physically based model to study the field scale and catchment scale effects of adding strips of trees in an intensively sheep farm region of the UK. Results from this study showed that flood peaks magnitudes could be reduced up to 40% at the field scale, and that the overland flow, which is a major contributor to peak floods, could be reduced up to 60% at a catchment scale of 12 km². The FRMRC is currently extending this study to larger scales, to determine if the effects of land management stay significant (Jackson et al. 2008).

Another example of the impacts of land use change at different scales comes from the Environment Waikato Regional Council, a New Zealand based government organization. A Technical Expert Panel (2010) studied the impacts on flood probabilities that converting 542 km² of forest into agriculture would have at different subcatchment scales (from 10 km² to 12420 km²) of the Waikato River watershed. They found that only under really high rainfalls (with return periods of 100 and 500 years) the land-cover conversion of this area would increase the flood probability at large spatial scales. However, the land-cover conversion of this area would significantly increase the flood probability at the local scale (10-100 km²) studied under all the rainfall return periods selected (5, 20, 100 and 500 years) (Appendix A). This study highlights that the impacts of land-cover change at different spatial scales varies (could be insignificant or significant) and that therefore, it is not possible to assume that local changes will be significant at the regional (catchment) scale.

The local and regional evaluation of land-cover change effects on flood risk are essential components of flood risk management projects, and shape policies and legislations in terms of spatial land-use plans. The understanding of how local changes can alter the risk of flooding at the catchment scale provides an important instrument for the development of optimal sustainable water resource strategies. Without this clear understanding, decision makers are not able to objectively demonstrate or predict the benefits of proposed policies, and therefore, it is not possible to estimate economical, environmental or social benefits of different policies.

6 Instruments for land-use planning and watershed management under model and climate change uncertainties

The predictions of the previous described studies include different levels of uncertainty, and governments need to interpret these uncertainties and make decisions on policies, land-use management, and responses. These uncertainties are the result of complex and unmeasured soil properties, unknown drainage networks (ditches, tiles, pipes), unknown channel and stream modifications, unspecified management practices (and difficulty of collecting this information at large scales). Even though not yet fully demonstrated, it has been hypothesized that more intense rainfall as a result of climate change can also increase the probability of floods (Beier et al. 2009). Appendix A presents a table that demonstrate how uncertainties on flood prediction are higher for more rare events compared to low return period events. Therefore, if more extreme rainfall events are expected, larger uncertainties predicting flooding extents can also be expected. In other words, large uncertainties of future climate predictions add to the uncertainties that need to be kept in mind when designing flood prevention/management plans (Bronstert 2004).

To reduce the consequences of rare events, structural and non-structural measures can be used. The first aims on decreasing flood occurrence probability, while the second endeavor the minimization of the consequences of floods. In the past, focus was given in the adoption of structural mitigation measures, involving the constructions of dikes, dams and embankments. These measures are usually very costly and only provide protection to a certain level of floods. The occurrence of higher levels floods than the structures were designed for, or the failure of a structure, could result in more damages than if the structure was not in place. Also, the structures give a sense of false security to developers and residents and encourage the urbanization of high risk areas. Besides that, this type of measures usually present a very high cost to the environment, causing the loss and deterioration of important ecosystems such as riparian wetlands.

Due to these fallacies, more attention has been paid to the reduction of the consequences of flooding instead of the development of very costly structures to reduce the probability of flooding. This means that instead of decreasing the probability of an event, the

new strategy is to minimize the consequences of flooding through the implementation of ecologically sustainable flood management in river basins. This new approach promotes the use of the natural dynamics and resilience of water systems as effective means to reduce the risks and damages associated with flooding in the long term. In this concept, some structural measures are still necessary, but non-structural measures aiming the protection, prevention, mitigation and response to floods at the river basin level are essential for the development of a sustainable flood management project. Some instruments to minimize the effects of land-cover change on flood risk are also considered, including the implementation of better land-use planning and better land management practices, maximizing natural vegetation cover, creating low risk flood storage areas and developing strong legislation.

Learning to live with floods through land-use changes and floodplain restoration is proved to create long term sustainability (Brouwer and van Ek 2004). Besides that, these methods present additional socio-economic and environmental benefits compared to traditional measures, including treatment of contaminants, restoration or recreation of natural habitats that can provide recreational opportunities and aesthetic values. Also, public awareness and appreciation of water system dynamics and resilience is increased, reducing the amount of illegal filling of the floodplain and reducing future damage.

7 Flood management in Europe and land-use: what did we learn

After 1998, Europe experienced over 100 major floods that caused the death of over 700 people. For this reason, the European Union created the Flood Risk Directive (FRD) in 2007. The main goal of the FRD is "to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activity." (European Commission for the Environment 2010). Under this Directive, EU member states need to identify areas that are under coastal and river flood risks, make flood risk inundation maps and design flood risk management programs. They also have to work cooperatively with other states that share river basins and take into account climate change and land use change into their long term plans. This Directive presents several challenges to the member states, since it requires cooperation between disciplines, and between countries. It also requires flood risk management programs to diverge from the way flood management was perceived

in the past, since they include ecological and cultural values that were not always included and that are hard to value and it challenges flood managers to go beyond protection to prevention. Even though the previous challenges can be perceived as nuisances, if the European countries assume this new flood risk management concept they could find new opportunities. For instance, Zevenbergen et al. (2008), present an example of a framework to redevelop many of the aged European infrastructures in a flood resilient way that not only provides safety and ecological benefits, but also economic benefits.

The flood risk management programs need to include the following components: prevention, protection, preparedness, emergency response and recovery and lessons learned. Flood prevention includes avoiding the construction of buildings in flood-prone areas, and modifying land uses and land management practices so they reduce flood risks; flood protection consists in using structural and non-structural methods that reduce the probabilities of floods; flood preparedness concentrates in educating the communities on their flood risks and helping them to respond in an optimal way during floods. It also defines the roles of the different institutions during the floods; emergency response plans include what should be done during the floods; and, finally, flood recovery includes returning to normal conditions, mitigating social, economical and environmental impacts, and analyzing what contributed to stabilize the situation and what made things worse, so these lessons can be applied to decrease negative impacts of future floods.

7.1 Netherlands and Belgium

Netherlands has always been threatened by floods due to its geographic location and landscape. More than half of the country's land area is situated below sea level and, if unprotected, it would be permanently threatened by flooding from the sea, rivers and lakes. Flood-prone areas in the Netherlands are protected against floods by a series of water defenses, including dikes, dunes, hydraulic structures and landscape works to guarantee high grounds. Many of the dike ring areas are below the sea water level, and safety standards have been established.

In 1953 a flood disaster of huge proportions caused by a combination of hide spring tide and windstorm reached Netherlands and England. The flood overwhelmed sea defenses and 2400 people lost their lives. After this disaster the Delta Commission was established to study alternative approaches for flood defense. The Commission designed proposals for new flood defense works and new safety standards for the entire country. For instance, Dantzig (1956) developed a general formula for the optimal level of flood protection through dikes, requiring investments at regular intervals. Every dike height is specified according to a design level with a certain exceedance probability, being all the current design criteria and the safety evaluation of flood based on these design levels. The height standards are established in the Flood Protection Act of 1996 and depend on the economic value of the area to be protected and the source of flooding (coast or river). For coastal areas, projects are designed to protect against floods with return periods between 4000 and 10000 years, while river basins are protected against floods with return periods between 1250 and 2000 years. The smallest return period specified was 250 years for some smaller dikes in the south-east of the country.

The Dutch agencies realized that implementing structural measures that would provide total protection for the communities located in hazard areas would be too costly. Following global tendencies, the recent Dutch approach aims on establishing measures to reduce the impacts of floods. In 1998, a new Dutch policy was published, including several recommendations for the development of an integrated water management policy. The document recommends increasing water system resilience, enhancing nature development, and improving the coherence between water policy, nature conservation policy and physical planning policy. This new policy also encourages including multiple stakeholders and the public at early stages of any project.

In a report published in 2000 the Advisory Committee on Water Management Policy stated that without additional efforts climate change and land subsidence will cause safety levels to decrease and water related problems to occur more frequently. In response, the government acknowledged the expected future problems pointed out by the Committee and published 'A different Approach to Water Management; Water Management Policy in the 21st Century' by the end of 2000. In this document land-use changes and floodplain restoration should be considered in conjunction with traditional structural measures in the solution to future water related problems.

The benefits of applying non-structural measures in Netherlands were demonstrated by Brouwer and van Ek (2004). These authors combined and integrated environmental, economic and social impact assessment procedures in a flood control policy decision-making support system for Netherlands. They evaluated the effects of alternative land-use and floodplain restoration policies using cost–benefit analysis (CBA) and multi-criteria analysis (MCA). They concluded that investments in alternative flood control policy, land-use changes and floodplain restorations, could be justified when including the additional ecologic and socio-economic benefits in the long run.

7.2 England and Wales

The most important financial and economical centers in England and Wales are located close to rivers and coasts, in areas with high flood risk. The high density of these countries, with more than 12% of its population living in flood-prone areas, increases their flood vulnerability and flood damages. Therefore, understanding and managing floods constitutes a priority for the UK.

The most notorious disasters in the United Kingdom occurred in 1953 and 2007, both with different characteristics. In 1953 floods were the result of high tides combined with very extreme meteorological conditions, causing the flooding of large coastal areas. In 2007 another big flood reached the region, this time as a result of rainfall events with very high intensity and frequency, occurring across extended regions. The hydrological conditions observed during the 2007summer season have never been recorded before. Floodplain inundations occurred across the whole England and Wales region, including many localized flash floods. These countries recognized their high flood risk and in response to this, several government programs to advance the understanding of floods and to decrease flood risks were created since 2004.

The Department for Environment, Food and Rural Affairs (DEFRA) launched in 2004 a new flood management strategy called Making Space for Water. Making Space for Water is the government's strategy to manage flood risks and reduce future economic, social and environmental flood damage, while promoting sustainable development. It is conceived as a holistic strategy that includes the participation of stakeholders in risk management, plans for climate change, and adopts a whole catchment and shoreline approach (DEFRA 2005). This strategy includes elements for land use planning, and rural, urban and coastal issues, so that the best practices that reduce flood and erosion risks are implemented. Making Space for

Water recognizes the value of non-structural measures on mitigating flood impacts. In this new directive the establishment of flood warning and response systems, improving of public awareness and education, and the adoption of restrict regulations for new constructions, are essential components of flood management projects.

The Flood Risk Management Research Consortium (FRMRC) was also launched in the UK in 2004, and it is currently in its second stage (the first stage took place between 2004 and 2008). FRMRC's goal is to enhance the knowledge in science and engineering to understand and improve urban and coastal flood risk, adequate land use management and real time forecasting (Flood Risk Management Research Consortium 2009). This consortium is integrated by several research universities, government agencies and consulting companies. The diversity of participants promotes the interdisciplinary research and fosters relationships between key national players. Some of the areas where the FRMRC has focused in are: developing instrumentation and models to make real time forecasting possible, researching how to manage defense infrastructure and how to develop effective communication techniques with stakeholders; developing models for urban flood management; and creating tools to deal with uncertainties. The FRMRC also has focused on land-use management and large scale experiments have been implemented to understand the effects of land-use management on flooding. In its second phase, the FRMRC is studying larger scale catchments, and including more land-use types and investigating lowland wetland management issues.

In 2008 the British Parliament presented the document 'Future Water – The Government's Water Strategy for England', where the strategies for flood protection are reviewed with the goal of adopting the principles of flood risk management. This document intends to establish a link between water and land management, and to propose new environmentally friendly measures for flood mitigation. The document emphasizes the risks of development in flood plains, and requires more collaboration between local authorities and national agencies to avoid such problems.

Recently The Flood and Water Management Act of 2010 was published with the goal of providing better, more comprehensive management of flood risks for people, homes and businesses. Among the key features of the Act is the establishment of the organizational hierarch responsible for flood risk management in the area, and the instruments for the participation of different stakeholders. In England the DEFRA has national policy responsibility for flood and coastal erosion risk management and administers grants for capital projects to local authorities and internal drainage boards. The Environment Agency (EA), a non-departmental public body of DEFRA, supervises all matters relating to flood defense including building and maintaining defenses and other management measures on designated Main Rivers, flood forecasting and warning, and improving public awareness of flood risk. The Department for Communities and Local Government (DCLG) is responsible for the development of planning policies and building regulations. DCLG also leads the government to help communities to recover from flooding and provide funding to local authorities through revenue support grants. This demonstrates the complexity of the governmental structure involved on flood mitigation. The achievement of optimal flood risk management projects is just possible if all agencies involved in the decision processes work in synergy.

The principles of flood risk management in England are (Green 2003):

1. Flood risk management is based on strategic planning (e.g., catchment flood management plans, shoreline management plans, asset management plans);

2. All floods should be managed and a regional approach for flood risk management should be taken;

3. Flood risk management should focus on maximizing the efficiency of catchment use instead of on minimizing flood losses (considering environmental impacts);

4. A multi-criteria analysis to define projects alternatives should be adopted;

5. Flood risk management should use qualitative risk analysis;

6. Flood risk management should address issues of social exclusion; and

7. Treat floods as processes and not states.

8 Course Events

Participants of the International Perspectives in Water Resources Science and Management course arrived in Delft, Netherlands on May 17th and for the next 2 weeks participated in a fast-paced cultural and technical immersion class.

During the 2010 IPH₂O class several flood research institutes were visited in the Netherlands. The class visited the UNESCO-IHE, Deltares and Delft Technical University. The class had the opportunity of learning about the physical and computer modeling being developed and used in these institutions. While in the Netherlands, the class also had the opportunity to visit few of the great engineering flood protection projects that are part of Deltaworks, including some of the sea dikes barriers and the storm surge barrier that protects the city of Rotterdam.

The class had the opportunity of visiting Flanders Hydraulic Research in Belgium. The Sigma Project (Flemish flood defense project) was presented during this visit, and tone of the ship hydrodynamics models was toured. After this visit, the class went on a tour of the Schelde River and visited one of the flood control areas constructed to provide flood protection and restore ecological habitats.

In the second part of the course, the class visited England and Wales. Several universities, engineering consulting companies and government agencies were visited. The universities visited were Cardiff University, the University of Bristol, and the Imperial College London. The class also visited HR Wallingford and Halcrow, which are engineering consulting companies largely involved with flood research. Finally, the Wales Environmental Agency and Department for Environment, Food and Rural Affairs (DEFRA) were also visited. Several of the talks in the UK concentrated in Emergency Response and communication with communities. During these visits couple physical models were toured and current research was presented. DEFRA did a demonstration for the class of the installation of portable flood walls. The last visit in the UK was to the Thames Barrier, which protects London from tidal and storms surge flooding.

The Netherlands, Belgium and UK have always been affected by large floods and it was enriching to learn from their long experience. Even though one of the main flood threats for these countries are coastal tides, which are not applicable to Iowa, Iowa has a lot to learn in terms of emergency preparedness and real time flood forecasting. These countries are also modifying their flood management plans to plan for the threat of increase flood risk due to climate change, and since this is not a common practice in the United States, a lot could be learned from their experiences.

9 Conclusion

The local effects of land surface changes on hydrological processes are already recognized. However, due to the high non-linearity of processes and changes of dominant hydrological processes with scales, the extrapolation of this knowledge for larger scales is not straightforward. This lack of knowledge adds uncertainties to the development of flood risks management projects at the catchment (regional) scale. Climate change and its effects on extreme rainfall events add even more complexity and uncertainty to the estimation of flood risks. This gap in knowledge is caused by the dependency of traditional flood frequency estimation methods on long series of historical data. Under non-stationarities caused by land cover and climate change the past no longer represents the future. In this case, knowledge can just be obtained with the application of calibration-free hydrological models that aim to reproduce physical processes across multiple scales. In this paper we describe the traditional models, and their main weakness. A calibration-free model that has the potential to be used to model hydrological processes under non-stationary conditions is also presented.

In the point of view of decision makers, actions to reduce flood risks have to be taken even if large uncertainties are presented. To mitigate flood disasters, governments use soft (non-structural) and hard (structural) flood protection measures. Europe has developed valuable knowledge in flood risk management, since it has been urbanized for centuries and it has been affected by large flooding events. The historical approach to flood risk management was the application of structural measures (e.g., dams and dikes), that only provide defense up to certain flood peaks and are very costly. When the design flood level is exceeded the false sensation of protection provided by these measures can cause large damage. Currently, flood risk management concentrates in non-structural measures that include: educating stake holders on flood risks, flood warning and response systems and adoption of best land use management practices, among others. These measures attempt to decrease vulnerability, increasing flood resilience.

This report was the result of what was learned during the "International Perspective in water science and management" course, held in UK and Netherlands in the year of 2010. The course theme was "Living with Floods" and the main goal was to learn how to deal with floods from the experience of countries that have been fighting floods for centuries. Even though a large spectrum of flood related subjects were covered during the course, this report

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focuses on how to deal with uncertainties on flood predictions, especially under nonstationarities caused by land cover and climate change.

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Appendix A.

Example of flood probabilities changes as a result of land conversion (Technical Expert Panel 2010).

	Small flood (5-year rainstorm)	Medium flood (20-year rainstorm)	Large flood (100-year rainstorm)	Extreme flood (500-year rainstorm)
Local flooding within Upper Waikato 10-100 km ² catchment area, 0-80% upstream land use conversion	Significant increase (5-50%) for streams where most of catchment has land use change	Significant increase (5-50%) for streams where most of catchment has land use change	Very significant increase (more than 50%) for streams where most of catchment has land use change	Very significant increase (more than doubled) for streams where most of catchment has land use change
Upper Waikato Taupo-Karapiro inflow 4405 km ² area, 542 km ² land use conversion (12%)	Little or no change	Little or no change	From 2-9% increase in peak flow rate (average 4%) 0-5% increase in 72-h flood volume (average 2%)	From 2-16% increase in peak flow rate (average 6%) 2-10% increase in 72-h flood volume (average 4%)
Upper Waikato Karapiro outflow 7852 km² area	Little or no change	Little or no change	From 0.5-3% increase in peak flow rate (mean of 2%)	From 1-12% increase in peak flow rate (mean of 7%)
Waikato River at Hamilton 8230 km² area	Little or no change	Little or no change	0-110 mm water level increase 0-21 m ³ s ⁻¹ peak flow increase	0-530 mm water level increase 0-140 m ³ s ⁻¹ peak flow increase
Waikato River at Ngaruawahia 11395 km ² area	Little or no change	Little or no change	0-40 mm water level increase 0-18 m ³ 5 ⁻¹ peak flow increase	0-270 mm water level increase 0-150 m ³ s ⁻¹ peak flow increase
Waikato River at Huntly 12066 km ² area	Little or no change	Little or no change	0-40 mm water level increase 0-17 m ³ s ⁻¹ peak flow increase	0-220 mm water level increase 0-150 m ³ s ⁻¹ peak flow increase
Waikato River at Rangiriri 12420 km ² area	Little or no change	Little or no change	0-30 mm water level increase 0-17 m ³ 5 ⁻¹ peak flow increase	Flood exceeds design standards even under current land use; stopbanks overtopped

Living with Floods

A Report for the International Perspectives Course TJ Middlemis-Brown



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Living with Floods represents a variety of concepts across the world. It translates into billions of dollars in flood control structures. It conjures images of people evacuated and lost capital. It means lives lost and crops destroyed. However, it also means rejuvenation of local soils, reconnection of rivers and floodplains, and recharge of alluvial aquifers. Flooding demonstrates a destructive event, but needed as a vital link in many ecosystems.

Living as Controlling (Tidal and Season Flooding)

The practice of attempting to control floods is common amongst industrialized nations. Industrialized countries often view floods as dangerous to citizens and hampering to economy growth. Unfortunately, flood plains are often the most productive areas of a country. Flood plains provide access to waterways for commercial trade, a water source for industry, rich agricultural land for farmers and close proximity to jobs for housing.

The Netherlands, a coastal European country, is a prime example of a country dependent on land existing in flood plains. It also exemplifies the productivity of flood plains being at an average of only 11 feet above sea level (Rosenburg) while having the highest gross domestic product (GDP) per square kilometer in Europe (Associated Programme on Flood Management). Furthermore, some working areas of the country would not exist without flood control structures. These areas sit at approximately 23 feet below sea level, making them extremely vulnerable to tidal and river flooding (CIA Factbook, 2010).

Building control structures has historically allowed the Netherlands to expand and exist as a country. The Frisians first began building levy structures almost 2000 years ago. Today, these structures have advanced to where the natural landscape has all but disappeared. However, storm and seasonal events have continued to wreak havoc for much of Dutch history.

The first recorded flood in the Netherlands occurred on 26 December 838 in the northwest part of the Netherlands (Van Baars & Van Kempen, 2009). However, the first major recorded long term inundation breached coastal barriers and occurred on 28 September 1014 (The first floods, 2004). Another major flood followed in 1134 AD (Van Baars & Van Kempen, 2009). Water flooded low-lying areas in the southwestern part of the Netherlands and created the Zuiderzee, or South Sea, with a complex of islands forming the Zeeland province. This was followed by 10 percent of the population losing their lives in 1287 from a levy-failure caused flood.

The Dutch people have continued to build up their flood structures for the past 800 years while suffering major floods, such as the Saint Elizabeth in 1404 and 1421, Saint Felix flood in 1530, All Saints flood in 1570 (The Delta Works, 2004), River Delta flood in 1595, Saint Marten's flood in 1686 and Christmas flood in 1717 (Van Baars & Van Kempen, 2009). However, the biggest engineered works and most well known floods came from the 20th century. The IJsselmeer Dam was built in 1933 in response to breached levees and flooding from the South Sea in 1912 (Van Baars & Van Kempen, 2009). Catastrophic levy failure occurred again on 1 February 1953, causing flooding in Zeeland and ending 1836 lives. This event inspired plans to close off the southwestern section of the Netherlands from the ocean.

Raising dike levels and closing off the "sea-arms" in the southwestern region of the Netherlands involved planning from various institutions within the country during the second half of the 20th century. A report concerning the "Economic Decision Problems for Flood Prevention," issued in 1956, detailed a review by the Delta commission, which consisted of the Central Planning Bureau, Royal Dutch Meteorologic Institute, Hydraulic Laboratory of the Technical University at Delft, Mathematical Centre at Amsterdam, and Public Works Department. The review contained new perceptions on dike construction and design. For example, dikes had previously been constructed based on the highest witnessed water level and without uniform national standardization. The commission drew on a Storm-Flood Committee conclusion focusing levy height construction on statistically probably sea level heights. Thus using the contemporary principles of exceedance probabilities to determine required dike height (van Dantzig, 1956).

Ultimately, the flood prevention report admitted the term "flood prevention" could be a misnomer. Not all floods can be prevented because the cost of every project has to be weighed against the benefits. Therefore, the goal of a flood control structure is to maximize protection versus monetary, logistical, and spatial constraints. For example, raising a levy an extra meter may change the exceedance probability from one in 1000 to one in 1500, but may be cost prohibitive by doubling the total structure cost.

The Dutch have built numerous flood and storm control structure since the 1950s based on the cost versus benefit principles. They consider economic costs in terms of buildings, land, materials, and lives lost. This has led to the implementation of the "Deltawerken," or "Deltaworks." These works both closed off, or in some locations created gates to close off, the sea from the "sea-arm" peninsulas and eliminated the need to renovate approximately 700 kilometers of levees (The Delta Works, 2004).

The first Deltawork, a barrier on the Hollandse Ijssel River, became operational in 1958. Two additional works, erected in 1961, closed the mouths of the Veerse Gat and Zandkreek. In the early 1970s, the Haringvliet sluices and Brouwers dam were constructed in relation to the Rhine River. The Eastern Schelde, considered an "open" dam, was built in the early 1980s to stop storm surges while allowing the natural tidal flow during normal conditions. The last major work built in the 1990s was the Maeslant Barrier, which was a set of movable gates outside Rotterdam (The Delta Works, 2004).

The Netherlands demonstrate a pinnacle of highly engineered water distribution systems. The landscape and local water processes bear little resemblance to a natural state. Several of the inlets converted from brackish to fresh water after building the sea walls. This ruined the local tidal aquaculture. Two inlets were kept under tidal influence only because one required access for shipping and the other had a fishing economy. Therefore, while the controlled system is impressive, it also begs the question whether there are issues with changing the landscape and ecology so drastically.

While the Dutch are the one of the most famous, various peoples have catalogued floods and attempted to control them throughout the world for thousands of years. The Egyptians began recording floods along the Nile River approximately 5000 years ago. They used a variety of devices to measure inundation levels, including stationary marks on quays (Bell, 1970). Instead of trying to control flooding,

the Nile peoples generally accepted flooding as a tool for agriculture instead of controlling it. This coexistance concept is discussed further in section two.

Ancient Chinese cultures began constructing dikes along rivers to keep floodwaters out of their farms and villages. Building levees on an immense scale required mammoth coordination of individuals, villages, and cities. They managed to completely disconnect the Yangzte River from its floodplain and open large swaths of land for settlement. The society level coordination helped result in the creation of a national identity, which is therefore partially attributed to dealing with the Yangzte and Yellow Rivers.

Issues have arisen from building dikes along the Chinese rivers. Disconnecting the rivers from their floodplains eliminated meandering and changed sedimentation patterns. Thus dredging is required to keep the riverbed from increasing in elevation. Raising riverbeds and channelizing rivers has led to floods like one in 1998 along the Yangzte, which killed 4150 people (Wong, 2010). The 1998 flood is a prime example of how dikes helped protect, until failing, people living in floodplains and also cause relatively small events, by squeezing the flow from an eight-year return interval event, to reach unprecedented stage elevations (Plate, 2002).

Structurally completed in 2006, the Chinese built the Three Gorges Dam in part to help alleviate flooding stress on dikes and create storage space after losing polders to an overcrowding population. The Three Gorges Dam spans across the Yangzte River to create a reservoir covering 1084 square kilometers (Rees, Waley, & Heming, 2001). Unfortunately, the sense of security from the dam can encourage people to settle in poor locations, just as the dikes allowed people to settle in areas originally reserved for use as polders.

Recent flooding in July 2010 affected 117 million citizens (CNN Wire Staff, 2010), almost one percent of China's population (Rosenburg, China Population, 2010). The first round of flooding caused an estimated 21 billion dollars in damage (CNN Wire Staff, 2010) with 701 dead and 347 missing from 645,500 collapsed homes. This devastation came from unusually large amounts of rainfall, which caused 70000 cubic meters per second discharge at the Three Gorges Dam. This discharge was 20000 cubic meters per second higher than the flood in 1998 (Wong, 2010).

The high flow at Three Gorges Dam was unexpected yet unusual precipitation and flows occur on a regular basis throughout the world. These extraordinary events are occasionally predictable and categorized during exceedance probability analysis. However, statistical probability is based on the local historical data population, which can be severely limited. Flood prevention is therefore a moving target and failures are a continued reality.

A recent dam failure on the Maquoketa River in Iowa illustrates the issues with flood exceedance and control structures inducing false security. The Lake Delhi dam incurred inordinately high flow after intense rainstorms on an already swollen river (Downstream Residents Dodge Bullet After Lake Delhi Dam Fails, 2010). Waters rose 15 feet higher than the dam outlets and eventually washed over the dam. The overtopping cut a hole in a weak section thus causing catastrophic failure. The flooding impacted residences and businesses downstream.

Ultimately the side effects of trying to control water movement may influence a policy shift. In fact, in some ways, policies in countries such as the United States (US) have begun to change. Dam removal and consideration of usable dam lifetimes have both become common practice. Instead of considering all water as an industrial resource to be shaped and controlled, the geomorphology and local ecology are being factored into planning and design. Other concepts, such as allowing flooding to occur while recognizing its potential local benefit, are also becoming common.

Living as Coexisting (Seasonal Flooding)

Overcrowding from population growth has generally pushed communities close to water bodies. Also, industry and agriculture relying on water sources for transportation, power and supply have crowded waterways. This close proximity to potential flooding created the need for flood control structures. Unfortunately, these structures disconnect a river from its floodplain and subject to failure. Therefore, possibilities for living with floods without, or with limited, flood control structures have been explored.

There are areas throughout the world where flooding has helped nurture cultures. For example, the Mekong and Chao Phraya watershed basins use flooding to grow rice. The natural flood patterns bring in the necessarily high levels of water in patties. Also, Egyptian cultures along the Nile River, as previously mentioned, thrived because floodwaters brought fresh, nutrient-rich floodwaters and sediment on a yearly basis. The culture grew around seasonal flooding and was able to sustain agriculture with limited artificial irrigation (Takeuchi, 2002).

However, floodwaters, while generally declining in effect with contemporary protective barriers, can be harbingers of death. Numbers of dead and missing dropped throughout the 20th century in locations like China. Floods in 1931, 1954, and 1998 caused, respectively, 145 thousand, 33 thousand, and 1320 either dead or missing. These were from 300, 60 and one levy breach. The reduced number of levy breaches corresponded with saved lives, but water levels stayed similar with each flood event while precipitation amounts decreased. Unfortunately, population growth in areas previously used for ponding and offsetting floodwaters caused the high water levels (Takeuchi, 2002).

Similar to China, The Netherlands has experienced population growth in water storage and flood prone areas. These areas, protected by dikes, provide citizens with a false sense of security. Raising the heights of dikes to accommodate changing exceedance probabilities has recently been criticized. This traditional approach of building tall walls to contain river water is being reevaluated in favor of an initiative known as "Room for Rivers," which reconnects the riverine channel with its surrounding floodplain by establishing empty, floodable areas on the riverbanks (van Stokkom & Smits, 2002).

Creating a space for river overflow helps exemplify the concept of living with floods. "Room for Rivers" stems from changing the paradigm from the "battle against water" to "living with water." This change is in part due to issues with raising dike heights, but is also attributed to a desire for healthier, more pristine riversides than those currently in existence. One study showed residents in the Beuningen region of the Netherlands had more of an ecocentric than anthropocentric viewpoint toward river management and most either living or spending time near the river felt attached to its well being (de Groot & de Groot, 2009).

Another solution to avoid residential flooding is transplanting. Rezoning flood prone areas as parks and recreation areas eliminates risk to businesses and residences. The park structures can be built for flooding using impervious, easily washable materials. To reduce local flood prone residences, Iowa City, Iowa purchased and demolished homes in the 100-year floodplain after the 2008 flooding in Iowa using the Federal Emergency Management Agency's (FEMA) Hazard Mitigation Grant Program (Smith, 2009). These areas are now being used as neighborhood parks.

Accepting flooding, attempting to build accommodating structures, and deciding where to locate displaced people requires some contemporary tools. One such tool is accurate mapping of flood prediction zones based on Light Detection and Ranging (LiDAR). These maps are currently being created in Iowa for the State Department of Natural Resources by the Iowa Flood Center, housed in IIHR-Hydroscience & Engineering, which is located in Iowa City and affiliated with the University of Iowa. The maps will illustrate 100- and 500-year flood zones across the state in both rural and urban areas. The new maps could be used for flood insurance, flood-friendly design, locating escape routes, etc.

The flood friendly designs allow residences to be built in map identified flood prone areas. Structures like building with concrete-only parking structures on the first level, floating houses, and homes built on pedestals. Floating houses (Even Construction) have been around for decades (Shaman, 1981) and recently showed up in New Orleans. One prototype house is built to typically rest on the ground with the capability float in up to 12 feet deep floodwaters (Floating House Makes Debut in New Orleans, 2009).

Trumping houses, a Dutch architect working in Dubai proposed received a commission to build floating islands, which allow people to live in a coastal area without getting inundated by rises in water levels (Palca, 2008). This is an advanced, but similar concept to the artificial hills created by farmers off of the northern coast of Germany (Plate, 2002). Another company, located in the United Kingdom (UK), is designing houses on pedestals capable of weathering floodwaters (Pivotal Construction, 2009).

Flood friendly building in the UK fits in with the amount of housing and commerce located near water. Approximately 10 percent of the population lives within 100-year floodplains with assets worth almost 400 billion dollars (Klijn, Samuels, & Van Os, 2008). The current strategy to mitigate flood damage involves limiting redevelopment in flooded locations, eliminating new development, and encouraging setting aside specific areas for floodwater storage. Thus the UK is working to reduce areas subject to flood damage while minimizing losses through risk assessment, widespread insurance, and warning systems.

Weighing the cost and accurate benefit value of flood control versus working with floods is gaining popularity among policy planners. Integrated Water Resource Management (IWRM) principles support the change. IWRM promotes receiving and using input from all stakeholders. For example, the real costs of losing local natural resources.

Living as Responding (Flash Flooding)

Controlling and coexisting with floods are generally viewed from the standpoint of seasonal and tidal flooding. Flash flooding differs from these types of flooding in temporal opportunity, forces involved

and location. Likewise, the response and methods for living with flash flooding have more to do with evacuation than creating protective barriers and designing compatible structures.

Seasonal floods often occur along rivers and streams after snowmelt engorges the local flow. Heavy rains add runoff to swollen rivers and overload the system. Weather forecasting services, such as the National Oceanographic and Atmospheric Administration in the US, generally provide forecasts offering multiple day warnings. Authorities use this time to establish evacuation routes and notify the public.

Flash floods are often single-storm driven. During a flash flood, dry, or low flowing, stream beds turn into raging torrents with 10- to 100-fold discharge levels. Designing control structures to deal with instantaneous loading, which carries strong erosive potential, is nearly impossible. The structures would have to be made of large riprap and concrete while lying dormant most of the year and causing channelization.

The instantaneous nature of flash flooding makes emergency response the best way to keep people alive. Flash floods represent the biggest direct danger to human life. Permanent structures are typically located outside the reach of flash flooding, with a few exceptions along urban streams and in rural areas, which translates into perfect recreational areas. Unfortunately, this can result in unwitting visitors occupying dangerous areas (Curtis, 2010).

A recent example of flash flooding disaster happened in June 2010 (Mayerowitz, 2010). The Caddo and Little Missouri Rivers, in southwestern Arkansas, rose 20 feet, peaking between one and two in the morning. The Albert Pike Campground, operated by the US Forest Service, was inundated by water rising at 8 feet per hour. The water level and debris flows caused 20 people to die, approximately 24 people to go to the hospital, and another approximately 60 people to require rescuing (Yancy, 2010).

Authorities noted a lack of warning likely exacerbated the devastation. The Little Missouri went from 3 feet in depth to 23.5 feet during the flood. The increase was caused by 7.6 inches of rainfall during the night. The cause and result are directly linked, but missing key was pre-emptive emergency response.

Creating a system to connect rain forecasting and local conditions to real time flood forecasting could have alerted local officials to the potential danger. From there, pre-emptive measures for flood response could have begun. Unfortunately, a study conducted in 1998 by the National Oceanographic and Atmospheric Administration warned against using remote sensing for flash flooding prediction. (Gilberto, Scofield, & Mentzel, 1998). However, as of July 2010, researchers at Imperial College in London are investigating a method to link storm forecasting to flood forecasting and, ultimately, to broadcast information potential flood victims. Social networking websites and services, such as Facebook, Twitter, SMS text messages, email, etc., present burgeoning opportunities for communication with the public and are being adopted by a new generation of US government officials (Rein, 2010).

The National Incident Management System (NIMS) provides a basis for government officials in the US to respond during a flood emergency (NIMS). Included within NIMS is the Incident Command System (ICS), which outlines an optimal method for organizing resources across multiple agencies. Wildfire emergency responses throughout the US are already successfully structured according to the ICS.

Applying this system to floods could help curtail confusion, especially in urban flooding situations where multiple jurisdictions are involved.

Flash flooding occurring in urban areas poses more of a threat to economic well being than lives. Authorities in the UK developed a system of temporary barriers against local storm and seasonal flooding. One example of these barriers is located in Bewdley, a town along the River Severn, where columns bolt to the ground and shutters close the gaps thus sealing businesses from the river (Flood defences go up in Bewdley, 2004). Unfortunately, similar barriers in the City of Worcester were stuck along a roadway during one flood event. The resulting flooding spurred concern for the reliability of moveable flood barriers.

Floating barriers are another possibility currently in consideration (Marshall, 2009). The barriers are lighter than water and sit in the ground while unused. They have yet to be deployed, but would eliminate issues with temporary structures getting stuck on the road to deployment. The floating barriers also avoid issues with blocking river views, which are important to the local businesses.

Conclusion

Living with floods, as a concept, varies by design and function. Societies have historically required water for commerce, agriculture, and general development. Consequently, floods are a part of human history and appear throughout historical text in terms of both disasters and mitigation attempts.

Controlling floods is a very industrial notion borne of modernization and human progress. However, the idea of working with floods to suit society's purposes, instead of fighting flooding, is gaining traction within communities. Hopefully, integrating rivers and communities will reconnect people with the local landscape and their waterways.

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International Perspectives in Water Resources Science and Management: UK and Netherlands, summer 2010

Project Title:

Modeling synthesis in hydro-science across continents; European perspective and American adaptation:

Lesson learned and looking forward

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Report organization

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Chapter 1: Background

1.1. International Perspective Program in IIHR, University of Iowa: Brief overview

-International Perspectives in Water Resources Science & Management (IPRWSM) is a study abroad program organized each year in a country or a world region for an intensive and indepth exposure to historical, cultural, social, economic, ethical, and environmental issues impacting water resources projects to prepare students for careers in a global marketplace. Since 1998, IPWRSM has focused on particular water resources projects in selected world regions, including the Narmada Valley in India, the island nations of Taiwan & Japan, the Three-Gorges Dam in China, the lower Danube River basin in Hungary, Poland and Romania, the Itaipu Dam on the border of Brazil and Paraguay, the Southeast Anatolia Project in Turkey, and the Nile River from Aswan Dam to the Delta in Egypt". (According to: *IPRWSM course website*)

IPRWSM course this year was organized by IIHR (in College of Engineering, University of Iowa) to Netherlands, Belgium and United Kingdom under the theme of Living with Floods'. The visit was hosted by some major foreign institute which includes: UNESCO- Institute for Water Education, TU-Delft (The Netherlands), University of Bristol, Cardiff University (United Kingdom) and Imperial College of London. Field visits were conducted to major coastal and riverine flood mitigation systems, structures and projects which includes: Sigma River Project (Belgium), Delta Works (the Netherlands), Severn Valley and Alkborough Flats (United Kingdom). In addition to it, meeting with faculty and students of the host universities and personnel from world-renown water resources research agencies were also arranged which includes: Deltares (Delft, The Netherlands), EPA Wales (Cardiff, UK) and HR Wallingford (Wallingford, UK).

1.2. Project report overview:

How much water do we have? How will it change in response to climate variation, human development patterns (land use change), and economic activities? Is the current water resources infrastructure adequate to maintain an adequate supply of water in long run? Answering these questions is a central challenge for hydrologic science and hence need a holistic approach which can enable linkages between different kinds of data, models and different domains. These grand challenges of hydrologic synthesis can be achieved through certain useful tools e.g. Open modeling framework (OpenMI) developed under European Harmon IT project; Hydro Desktop (an American adaptation) and these tools are reviewed in this study.

The **OpenMI** standard defines an interface that allows time-dependent models to exchange data at runtime. When the standard is implemented, existing models can be run in parallel and share

information at each time step. The aim of the OpenMI is to provide a mechanism by which physical and socioeconomic process models can be linked to each other, to other data sources and to a variety of tools at runtime, hence enabling process interactions to be better modeled.

New generation of synthesis tools like **HydroDesktop** from CUAHSI group is also reviewed in this study. Hydro Desktop is a new component of the HIS project intended to address the problem of how to obtain, organize and manage hydrologic data on a user's computer to support analysis and modeling. Hydro Desktop is focused on facilitating the discovery and access of hydrologic data and providing support for data manipulation and synthesis. It also provides data export to selected model-specific data formats, linkage with integrated modeling systems such as OpenMI.



Figure 1: Hydro-synthesis across boundaries

The mission of the proposed study is to learn, understand existing hydro-synthesis approaches and make observations, recommendations in dealing with the future challenges in hydro-science. In addition to it, author wants to utilize the knowledge gained through interaction with international peers in host institutes and proposes a framework for a model integration approach (through OpenMI, HydroDesktop platform) that is expected to contribute towards his future research goals.

1.3. Why do we need an Open Modeling Interface?

Modeling of environmental systems is challenging in part because process interaction often spans several disciplines, making it difficult to model integrated system response. No single model can represent all aspects of an environmental system as accurately as a conglomerate of model components created and maintained by experts in each field. Specific processes within the hydrologic cycle, for example, can be linked together using componentbased modeling, without having extensive knowledge of the inner workings of each computational module. Such a modeling interface and environment should resolve or improve a number of complicated linkage issues, such as for example: difference in spatial and temporal scales, feedback loops, differences in spatial and temporal concepts (distributed vs. lumped, steady state vs. dynamic), different units and naming of variables, distributed computing, etc.

The *OpenMI Interface* is a standard interface that enables OpenMI components to exchange data as they run. A linkage mechanism, such as the OpenMI, is the key to moving single domain modelling to integrate modelling and integrated modelling from a research exercise to an operational task. It will allow for integrated water management to be put into effect.

1.4. OpenMI Framework: Brief Overview

1.4.1. What is OpenMI? The OpenMI standard defines an interface that allows time-dependent models to exchange data at runtime. When the standard is implemented, existing models can be run in parallel and share information at each time step.

1.4.2. OpenMI Aims and Objectives: The aim of the OpenMI is to provide a mechanism by which physical and socioeconomic process models can be linked to each other, to other data sources and to a variety of tools at runtime, hence enabling process interactions to be better modeled.

1.4.3. How can models exchange data, what data and when?

Components in OpenMI are called LinkableComponents. Data transfer begins in OpenMI when a LinkableComponent requests data of another LinkableComponent via the GetValues method. In a two-way system, the data provider does not run forward in time until it receives this data request. Once it does, the component runs forward in time, stops, and converts its data onto the grid or location of the requesting LinkableComponent. Data can be exchanged through exchangeable model quantity which are variables accepted or provided by a model. This exchange can happen at the nodes or elements. Elements are the locations where quantities are measured. Following figures explain this more clearly.



Figure 2a, 2b and 2c: How, when, where can model exchange data and what kind of data

1.4.4. OpenMI features:

A. The OpenMI standard interface: An interface defines how a program interacts with an object; an interface includes properties and methods (functions). The OpenMI defines a standard interface that has three functions:

- **Model definition:** Define quantities a model can exchange, and at which elements can it exchange them.
- Configuration: Define which models are linked in terms of quantities and elements.
- Runtime operation: Enable the model to accept or provide data at run time.

B. OpenMI is 'interface-based': Its _standardized' part is defined as a software interface specification. This interface acts as a _contract' between software components. The interface is not limited to specific technology platforms or implementations. By implementing this interface a component becomes an OpenMI compliant component.

C. OpenMI is 'open': Its specification is publicly available via the Internet (www.OpenMI.org). It enables linkages between different kinds of models, different disciplines and different

domains. It offers a complete metadata structure to describe the numerical data that can be exchanged in terms of semantics, units, dimensions, spatial and temporal representation and data operations. It provides a means to define exactly what is linked, how and when. Its default implementation and software utilities are available under an open source software license.

D. OpenMI is a 'standard': It standardizes the way data transfer is specified and executed. It allows any model to talk to any other model (e.g. from a different developer) without the need for cooperation between model developers or close communication between integrators and model developers. Its generic nature does not limit itself to a specific domain in the water discipline or even in the environmental discipline.

Chapter 2. Hydrologic synthesis: European perspective

2.1. OpenMI framework: Development stages

The first version of the OpenMI has been developed by a team drawn from 14 organizations (lead by HR Wallingford, UK) and seven countries co-funded through the European Commission's Fifth Framework programme under contract number EVK1-CT-2002-00090 (the HarmonIT project). Steps and stakeholders in OpenMI development are discussed in brief here:

(a) European Commission (EC): Executive body of EU Proposes and implements legislation One Commissioner from each member state (http://ec.europa.eu/)

(b) Water Framework Directive (WFD): Most substantial piece of EC water legislation to date which was enacted on December 22, 2000. It defines **standards** and **procedures** and requirements for whole catchment modeling within 2015 across Europe Unions. (http://ec.europa.eu/environment/water/water-framework/index_en.html)

(c) Fifth Framework programme (FP5): Prioritizes EU research, technological development and demonstration activities (1998-2002). It allots about 15b euro for implementation of programs in following area: Quality of Life and management of living resources, User-friendly information society and Competitive and sustainable growth

(d) HarmonIT: Supported by FP5's Energy, environment and sustainable development program. It objective is to develop, implement and prove a system to simplify the linking of models to support whole catchment modeling (http://www.harmonit.org/)

As an outcome of intellectual collaboration amongst the above agency and projects, OpenMI framework came into existence in early 2002.

2.2. OpenMI adaptation, migration and applications:

2.2.1. OpenMI SWAT adaptation at UNESCO-IHE, Delft

(Based on: <u>Integrated Sediment Transport Modeling Using OpenMI (SWAT and SOBEK-RE)</u> for the Blue Nile River Basin' Presented by Getnet Dubale Betrie at 2009 SWAT conference at Boulder, Colorado)

Migration of SWAT 2005 into OpenMI: The key requirement for migrating a legacy model into the OpenMI framework is structuring the computing core to initialize, compute and finalize procedures and to allow the model to run one time step at a time. SWAT has all the mentioned

structure except that the initiation step is done by several modules. Therefore initiation process needs to be structured into one function.



Figure 3a and 3b. Wrapping SWAT model engine and OpenMI SWAT interface

Steps followed by Betrie et al are:

(a). Modified SWAT to run one time step at a time instead running daily loops within yearly loops. The time step in SWAT runs in a loop from the beginning of the simulation year to the end and loops everyday of the 365 or 366 days of the year.

(b). Then they created a C# class that implements the ILinkableComponent interface to rap the SWAT model engine. The process involves includes creating SwatDLL, SwatNativeDLL, SwatDllWrapper and SwatEngine classes.

(c). Next they built a C# class that implements the ILinkableComponent interface to wrap SWAT model engine. SWATDLL is the SWAT engine core.

(d). Created SwatNativeDLL class that translates function exported in FORTAN in to C# method.

(e). Then SwatDllWrapper class was converted into FORTAN convention e.g. array index into C# and error message into .Net exception. SwatEngine class implements IEngine interface.

2.2.2. Ongoing OpenMI-ISIS migration work at Halcrow, UK

(Based on: Release notes on Halcrow website)

Objectives of OpenMI-ISIS project: the main objective is to make ISIS compliant with OpenMI standard and itself as a product of software that can be used by modelers to integrate ISIS model with other models. The final _result' would be a kind of _adds-on' component to ISIS software and be ready to be used by modelers.

The following items describe the procedures:

(a). The engine core will be transformed into a DLL file which will be further used in the development of OpenMI-ISIS.

(b). Implementation of the missing classes will be done that are needed for the migration of ISIS

(c). Test applications for the written codes will be done

Expected outcome: Based on the research work, the following outcome is expected to be obtained: Migration of ISIS OpenMI compliant in terms of computer codes and further testing report for the codes that have been written. It is expected to integrate model examples-linking ISIS to other software (e.g. Infoworks CS) once this migration is done.

2.2.3. Applying OpenMI framework for understanding hydrological and climate model interaction at DHI, Europe

In a novel approach to represent the coupling between the land surface and atmosphere, DHI and DMI (Danish Meteorological Institute) are exploiting OpenMI technology to link hydrological and climate models. Modeling the effects of climate change on the hydrological cycle requires a proper understanding of the water and energy exchange between the atmosphere and the land surface. This exchange is a process that can have a significant impact on the hydrological cycle under a changing climate. OpenMI provides a practical way of linking the achievements of the meteorological and hydrological modeling community.



Figure 4. Integrated MIKE SHE model framework

To develop improved methods for assessing the effects of climate change on water resources, a coupled hydrological and climate modeling system is being developed using two state-of-the-art model codes: the climate model code HIRHAM and the hydrological model code MIKE SHE. OpenMI technology is used to link these two existing model systems. This work is being carried out in the HYACINTS project supported by the Danish Strategic Research Council.

Therefore, OpenMI is ideally suited to linking hydrological and climate models and allows linking with different spatial and temporal representations and across different platforms.

(Source: DHI website)

Chapter 3. American context: Lesson learned

3.1. Open Modeling Interface in American context: HydroDesktop

HydroDesktop is a free and open source Geographic Information Systems (GIS) application that helps to discover, use, and manage hydrologic time series data. The GIS components are built from MapWindow 6, while the time series components utilize web services designed by the CUAHSI Hydrologic Information Systems (CUAHSI-HIS) project.

3.1.1. Key Components: HIS Desktop is being developed as a client-side (desktop) software tool that ultimately will run on multiple operating systems and will provide a highly usable level of access to HIS services. The software is envisioned to provide many key capabilities of existing HIS tools (data query, map-based visualization, data download, local data maintenance, editing, graphing, etc.) as well as new capabilities not currently included in any of the existing HIS components (data export to some model-specific data formats, linkage with integrated modeling systems such as OpenMI, and data upload to the HIS server from the local desktop software).



Figure 5. HydroDesktop configuration in HIS (Source: CAUSHI website)

3.1.2. Key Functionality:

A. Data Discovery: HIS Desktop supports two different methods of data discovery: (1) ontology-based discovery across all WaterOneFlow web services that have been registered at HIS Central and for which metadata has been harvested and stored in the HIS Central metadata catalog; and (2) Discovery of data within a single WaterOneFlow web service that has not been registered at HIS Central.

B. Data Download: The goal of the HIS Desktop data download functionality is to retrieve observational data series that have been identified for download using the data discovery tools described above and to create a local cache copy of the data in the desktop data database. Through the underlying MapWindow GIS components (version 6), HIS Desktop can connect to, download and display GIS datasets published using OGC Web Feature Services (WFS), Web Coverage Services (WCS), and Web Map Services (WMS).

C. Data Visualization, Manipulation, and Export: HIS Desktop supports visualization of both geospatial and time series data. Geospatial data visualization is enabled through an interactive GIS map using the open source MapWindow GIS components (Ames et al. 2008) and 3rd party MapWindow plug-ins. Visualization of observational data is provided through a variety of plots using the open source Zed Graph plotting package and is focused on exploratory data analysis for data series that are downloaded and stored in the HIS Desktop data repository.

3.2. HydroModeler

HydroModeler is a HydroDesktop Plug-in for integrated modeling that provides OpenMI compliant access to data stored in HydroDesktop. It includes following features: (1) The DbReader and DbWriter components provided with HydroModeler can be reused within any OpenMI-compliant system; and (2) –plug-and-play" modeling system in order to improve model transparency and adaptability



Figure 6. HydroModeler configuration in CUASHI HIS (Source: CAUSHI website)

3.3. OpenMI: Critical review, issues and future enhancements:

3.3.1. Review of other integrated modeling frameworks

Many integrated modeling frameworks already exist, and new ones seem to be invented per project. A few well known solutions are:

(a) OMS: _Object Modelling System' is a pure Java, object-oriented modeling system framework that enables interactive model construction and application based on components. It is a collaborative project active among the U.S. Department of Agriculture and partner agencies and organizations involved with agro-environmental modeling.

(b) MODCOM: This framework facilitates the assembly of simulation models from previously and independently developed and tested component models. A small, but dedicated group of developers build the MODCOM software and it is distributed under the terms of the GNU General Public License, available at http://www.modcom.wur.nl.

(c) TIME: This is an Invisible Modelling Environment with software development framework for creating, testing and delivering environmental simulation models. TIME includes support for the representation, management and visualization of a variety of data types, as well as support for testing, integrating and calibrating simulation models.

While all modeling frameworks simplify the task of creating models, by providing reusable components for data handling, visualization and model execution, TIME further simplifies the task by providing a high level, meta data driven environment for automating common tasks, such as creating user interfaces for models, or optimizing model parameters. This reduces the learning curve for new developers while the use of commercial programming languages gives advanced users unbridled flexibility. (Link: http://www.toolkit.net.au/Tools/TIME).

(d) KEPLER: It is a scientific work flow application designed to help scientists, analysts, and computer programmers create, execute, and share models and analyses across a broad range of scientific and engineering disciplines. Kepler can operate on data stored in a variety of formats, locally and over the internet, and is an effective environment for integrating disparate software components, such as merging "R" scripts with compiled "C" code, or facilitating remote, distributed execution of models. Using Kepler's graphical user interface, users simply select and then connect pertinent analytical components and data sources to create a "scientific work flow"—an executable representation of the steps required to generate results. The Kepler software helps users share and reuse data, work flows, and components developed by the scientific community to address common needs (Link: http://kepler-project.org/).

3.3.2. OpenMI Critique

Based on Knapen et al 2009 study, following observations can be made about OpenMI: (1) since it is less bound to a specific environment it is a good candidate for cross-framework linking and

supporting multi-framework models; and (2) Compared to other parallel frameworks (e.g. OMS, MODCOM, TIME, KEPLER) the OpenMI is the youngest and thus a bit less evolved. On the other hand it has the unique feature that it in principle only sets a standard based on interfaces, currently defined for both the .NET and the Java languages.

3.3.3. Future enhancements

There are many more interesting areas to research and potentially include in the OpenMI. Based on Knapen *et al* 2009 study, a few current ideas are:

(a) Increased use of semantic information to describe components and exchange items. By using ontology the OpenMI would better fit into the semantic web world and, for example, reasoning engines could be used to facilitate model integration. Some steps towards this have been taken in the SEAMLESS project.

(b) Combining the previous two points together with merging the web standards for Service Oriented Architecture (SOA), like UDDI, WSDL and SOAP, in general could make using models within an enterprise or across organizations easier. Users could be assisted (semi-automatically) in finding and selecting models and creating mash-ups of them.

(c) On the SDK side of the OpenMI, working with it could be made less invasive, for example following approaches from other frameworks like Spring (http://www.springsource.org) and Hibernate (http://www.hibernate.org), e.g. by using plain classes and annotations or XML configuration files to use them with the OpenMI.

Chapter 4. IPWRSM course: Lesson learned and looking forward

4.1. Some future research ideas inspired through IPWRSM program:

OpenMI is on its way to become a global standard for model linkage and data exchange in the environmental domain. Through this course some interesting research ideas have been generated, as proposed in following section, which author wants to persuade and explore as part of his future research:

(a) Building a framework for coupled Climate and Hydrological modeling

Motivation: For understanding the effects of environmental changes on local watersheds, linkages between climate and watershed models need to be done. Such framework can essentially address emerging questions about climate change impacts in a holistic way. This proposed work is inspired from similar work ongoing in climate modeling community.

In this proposed study the hydrological model chosen will be _Soil Water Assessment Tool' (SWAT). It is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds. Inputs to SWAT include weather variables such as maximum and minimum temperatures, daily precipitation, relative humidity, solar radiation data, and wind speed data. On the other hand climate model chosen will be CAM which is part of the Community Climate System Model (CCSM). A case study will be done for Clear Creek watershed in state of Iowa.

Framework configuration: This coupled system will comprise of three main components: hydrological model _SWAT^c, atmospheric model _CAM^c, and a driver application. The atmospheric model will be wrapped with an OpenMI interface, which will facilitate the communication with the OpenMI-compliant hydrological model. Wrappers for both SWAT and CAM will provide OpenMI interface to each model. Driver (OpenMI Configuration Editor) will use OpenMI interface to time step through models via wrappers.



Figure 7. Coupled Climate-Hydrological modeling Framework

4.2. Concluding remark:

International Perspectives in Water Resources Science and Management (IPWRSM) 2010 course was a great opportunity to interact with the peers from some of the world's best known Institutes. Knowledge gained through exchanging views and ideas with peers abroad will be valuable for author's future research and will help him in growing as a researcher.

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INTERNATIONAL PERSPECTIVES IN WATER RESOURCES

SCIENCE AND MANAGEMENT:

LIVING WITH FLOODS

Hydroinformatics: Data Mining's Role in Hydrology and a Virtual Tipping Bucket Framework Motivated from Studies Abroad

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Abstract: The hydrological challenges we face, such as water quantity and quality, and understanding the effects of human intervention in the ecosystem (land use) have recently been approached with a brand new set of tools than were previously available. These tools have risen from the data rich, and well networked, environment that is available globally in many areas. From this environment came rise to the fields of data mining and hydroinformatics, which use heuristic algorithms to find patterns in datasets for model building and prediction. Often, these data driven models have an accuracy that could not be achieved with physics based ones.

The University of Iowa's 2010 International Perspectives in Water Resource Science and Management: The Netherlands, UK provided students the opportunity to communicate with international colleagues, and share ideas, tools, and experiences with experts in the field. Data mining and hydroinformatics was discussed thoroughly in the course, as well as the need for high resolution radar data for the betterment of hydrological models. This high resolution radar data could be achieved using data mining techniques, such as a neural network, to train radar reflectivity measurements for targeting precipitation gauge measurements. The radar data would then substitute physical tipping bucket rain gauges, and the data driven model act on the data to create —irtual tipping buckets" at the spatiotemporal resolution of the NEXRAD system.

This paper gives a brief overview of hydroinformatics, some applications of data mining in hydrology, lessons learned in the IPWRSM course, and the framework and preliminary results of virtual tipping buckets, as well as future research directions inspired the study abroad.

I. Introduction

As we exist in the information age, a wealth of data is available now that has never been. Tools such as remote sensing, in situ instrumentation, and online monitoring/internet are accredited for this abundance of data. This information still requires better interpretation to be fully utilized. Data mining builds models from data uses unique algorithms to make forecasts with unparalleled accuracy.

Since the early 1990's knowledge discovery and data mining (KDD) has become a popular choice for finding patterns in data. Data mining's (DM) grass roots were in economics, but have since branched into countless other fields, to include social pattern analysis, chemistry, hydrology, medical fields, systems, and has many web-based applications, such as Netflix selections and Pandora Radio. KDD has been recently applied to areas where physics-based or deterministic models have once been preferred. The reason for DM's success is its ability to find complex patterns in data sets to very accurately build models with algorithms that can describe highly nonlinear phenomenon.

KDD applications in hydrology have opened a new field called hydroinformatics, which applies data and communication systems for hydrological issues and research. DM has found success in studies of flood prediction, water quality, and radar-rainfall estimation.

1.1. Hydroinformatics (Dr. Demitri Solomatine, UNESCO-IHE, Delft)

Demitri Solomatine of UNESCO-IHE, Delft, is an expert in the field of hydroinformatics and was a key speaker in the IPWRSM course. In his *Hydrological Sciences Journal* editorial, –Hydroinformatics: Computational Intelligence and Technological Developments in Water Science Applications," he provides an insightful overview of the field.

Professor Mike Abbott is credited with coining the phrase hydro-informatics in his publication titled only by his new cleared phrase, –Hydroinformatics" in 1991. Hydroinformatics is rooted in computational hydraulics, and was thus established as a technology for numerical modeling and data collection, processing, and quality checking (Abbott & Anh, 2004; Abbott *et al.*, 2006). In the past 15 years hydroinformatics has aimed to use data-driven techniques for modeling and prediction purposes. Most of these techniques were adopted from computational intelligence (CI)/intelligent systems/machine learning. Neural networks, evolutionary algorithms, and decision trees all were initiated in this field before they crossed over to hydrology.

Although some of the processes for creating physics-based models are very similar to those required to generate data-driven ones, hydro-informatics has not been received by the hydrological community without resistance. Data acquisition occurs in the building of both physics-based and data-driven models, but hydro-informatics has brought

some different terminology from its CI roots. For conceptual model builders, this data is used for calibration. For a data-driven modeler, it is used for training/validation. Essentially, these two processes are the same.

However, the difficulty in extracting scientific knowledge from a seeming incoherent data-driven model has although hindered their acceptance into the hydrological world, although there have been well constituted, successful efforts to unravel the hidden knowledge within data-driven techniques (Wilby *et al.* 2003; Elshorbagy *et al.* 2007).

However, hydro-informatics' true purpose may be to aid physics-based models in operation. In fact, hydroinformatics was not created to breed further understanding into hydrological processes directly, but instead to take advantage of the vast archived records, streaming real-time data, and well integrated communication systems that have been recently ubiquitous, and apply these resources for hydrological issues and research. Data driven-models should therefore be closely associated, and preferably linked, to physics-based ones.

1.2. Data Mining Applications in Hydrology

1.2.1. Discharge Modeling

Demitri Solomatine, an expert in the field of data-driven approaches to modeling and prediction in hydrology and also one of the speakers in the IP course, has published multiple works documenting the success of these methods.

In his collaborative work with Dibike (2000) he created two NN's, a multilayer perceptron (MLP) and a radial basis function (RBF), trained with concurrent and antecedent rainfall and discharge data to model the current discharge of the Apure river in Venezuela. Both the NN's outperformed a conceptual rainfall-runoff model, with the MLP slightly outperforming the RBF. Solomatine concludes from his study that the optimal number of antecedent rainfall/runoff parameters (memory parameters) should be discovered before the final simulation, otherwise known as feature selection, and also that the RBF was slightly out performed in accuracy by the standard MLP, but the RBF took less time to execute.

In his study with Bhattacharya (2005) he used NN's and modeling trees to predict river discharge from stage height. The models were trained with discharge and stage height memory parameters to model the current discharge. The resulting models were much better at predicting the current discharge than the traditional rating curve fitting method. The authors suggest that these data-driven models are more successful because they better represent the looped-rating curve, a phenomenon where discharges at a given stage height are higher for rising water levels than for falling. This phenomenon is partly responsible for the error in the rating curve formula, $Q = \alpha (h - h_0)^{\beta}$.

1.2.2 Flood Prediction

Damle and Yalcin (2006) utilized time series data mining (TSDM) for flood prediction, but claim their methodology is generalizable and applicable to other geophysical phenomenon such as earthquakes and heavy rainfall events. Their proposed TSDM methodology is demonstrated using data from a St. Louis gauging station on the Mississippi River. The data was discretized about a discharge threshold; those instances of higher discharge than this threshold were classified as —flood event." Each element of the data was clustered. This clustering was done considering the element's previous values, or memory parameters (ie t-1, t-2, t-n where t is the element's observation time), as its attributes. A memory parameter is a previous value of a data point set back by a number of time steps by its memory (t-1, t-2, ..., t-n) and this grouping was set by a user-defined parameter, beta. This data set used included two floods, and the proposed method did not start to miss a flood until the prediction time increased to 7 days.

1.2.3. Water Quality

Water chemistry systems are highly complex and are difficult for physical models to capture. Recently, data-driven techniques have been applied with success in water quality. Work by Sahoo *et al.* (2009) used a NN to predict stream water temperature which is a dominant factor for determining the distribution of aquatic life in a body of water, as many of these biological factors are temperature dependent. In this study memory temperature and discharge memory parameters were used to predict the current stream temperature at a gauging station on four streams in Nevada. The backwards propagation neural network (BPNN) outperformed the other models it was tested against, a statistical model (multiple regression analysis) and the chaotic non-linear dynamic algorithms (CNDA).

Other data-driven studies in water quality modeling include using a fuzzy logic model to predict algal biomass concentration in the eutrophic lakes (Chen and Mynett (2001)), creating a NN centered decision-making tool for chlorination control in the final disinfecting phase (Sérodes *et al.* (2000), and establishing a water quality evaluation index by way of a self-organizing map NN.

1.2.4. University of Bristol

Work from this university focused specifically on data mining in data mining for improving the accuracy of the rainfall-runoff model for flood forecasting. The work discussed key issues such as selecting the most appropriate time interval of the data set for data mining. A case study was performed in four different catchments from Southwest England, using an auto-regressive moving average (ARMA) for online updating. The study concluded that a positive pattern existed between the optimal data time interval and the forecast lead time is found to be highly related to the catchment concentration time. The work used the information cost function (ICF) for calibration and

determination of which features provide the most information to the model. The mathematical formulation of the ICF can be seen below in equations 2-5.

$$E_{j} = \sum_{k} S_{k}^{j2} \qquad (1)$$

$$E_{j} = \sum_{k} C_{k}^{j2} \qquad (2)$$

$$P_{j} = \frac{E_{j}}{\sum_{j} E_{j}} \qquad (3)$$

$$ICF = -\sum_{i} P_{j} ln P_{j} \qquad (4)$$

Where E is energy, S is approximation, C is detail, and P is the percentile energy on each decomposition level.

The authors stated the course of their future work was towards using the information cost function (ICF) for calibration data selection (feature selection) and to verify the hypothetical curve of the optimal data time interval.

II. Virtual Tipping Bucket (VTB)

The spatiotemporal resolution of current radar system is far superior to the simple point measurements that are available with precipitation gauges. The National Weather Service's (NWS) Next Generation Radar (NEXRAD) system is comprised of 137 radar sites in the contiguous United States, each of with is equipped with Doppler WSR-88D radar capable of producing high resolution reflectivity data (from -20 dBZ to +75 dBZ), making a full 360 degree scan every 5 minutes, with has a range of ~230km and a spatial resolution of about 1km by 1km (Baer, 1991).

The main disadvantage of NEXRAD is that its precipitation estimates are prone to many sources of error. Blockage by mountains and hilly terrain, confusion with flocks of birds and swarms of insects, anomalous propagation and false echoes, and signal attenuation are all sources of error to radar observations. Furthermore, algorithms for converting reflectivity to a rainfall rate are inaccurate. The well accepted Marshall-Palmer method for Z-R conversion describes a relationship between reflectivity (Z) and rainfall rate (R) but is prone to error due to this exponential relationship. Equation 1 describes this relationship.

$$Z = a \cdot R^b \tag{5}$$

Rain gauges give a real measure of what precipitation fell, but are only single point measurements. Also, their values may be different from those at another gauge only a few kilometers away, especially during the convective season where an unstable atmosphere is capable of very high precipitation rates at one location, and no precipitation at another. If the two systems were merged, the strengths of each could be benefited. This could be done by training a neural network (NN) with NEXRAD reflectivity data to target precipitation values at tipping buckets covered by the radar.

2.1. Data Mining Applications in Radar-Rainfall Estimation

There have been few attempts to make this link between radar data and tipping bucket data with data-driven techniques. A paper by Teschl *et al.* uses a feed forward neural network (FFNN) and rainfall estimation using radar reflectivity at four altitudes above two available rain gauges. In this work a feed forward neural network (FFNN) is trained with reflectivity data for rainfall rate prediction at two rain gauges. Despite the mountainous, Austrian terrain, good results (mean squared error <1mm/15min) were still achieved, even though the radar was situated 3 km above the rain gauges. One obstacle to the research was that due to the, the radar gauge sat 3km above the tipping buckets, making it impossible to detect low level moisture. The algorithm had a mean absolute error (MSE) of less than 1mm/15 min and outperformed the Z-R conversion

Trafalis *et al.* used a 5 x 5 grid of radar data at the lowest 5 elevation angles (0.5 deg to 3 deg) above a Norman, OK rain gauge. This study considered some different parameters such as wind speed and bandwidth to complement reflectivity, but with unimproved results. The best performing models in the study all had MSE's less than 0.1 mm/hr.

Liu *et al.* (built a recursive NN with a radial basis function (RBF) that would continuously update its training data set with time. The authors chose a 3 x 3 radar grid (1km resolution) at 9 elevations as the input and targeted values at a tipping bucket. The mean rainfall estimation for the recursive NN was more accurate than the standard NN and also more accurate than the Z-R conversion method.

III. International Motivation for the VTB

The necessity of high resolution precipitation data was emphasized throughout almost all of the presentations of the IPSWRSM course, but some focused more specifically on the use of radar data, precipitation gauges, and datadriven techniques to achieve this goal. Students from the Imperial College in London showed a strong interest in this topic, and provided a strong motivation for the development of a VTB system.

2.1. Imperial College London (Under Professor Čedo Maksimović)

Dr. Christian Onof and Li-Pen Wang's study on urban pluvial flood forecasting requires high-resolution rainfall forecasting with a longer lead time. The approach would combine using downscaled numerical weather prediction (NWP) models and radar imagery (nowcasting) with high spatial and temporal resolution. This information will then be used for the calibration of the ground rain gauge network. The figure below from their presentation is useful to show the methodology of their project.



Fig. 1. Pluvial flood forecasting data processing methodology schematic

The experimental site for the project is Cran Brook catchment in the London borough of Redbridge, with a drainage of approximately 910 ha (9.1 km² which is considerably smaller than the Clear Creek Basin (250 km²)). The catchment enjoys radar coverage from two separate stations and three real-time tipping bucket rain gauges with observation frequencies of 1-5min.

One student aims to develop and test advanced tools capable of obtaining accurate and realistic simulations of urban drainage systems and flood prediction. To do this, improving the analysis of existing rainfall data obtained by rain gauge networks radar (fine scale resolution) is considered a main objective. Three tipping buckets are utilized and the study intends on establishing their own Z-R conversion to create quantitative precipitation estimates grids.

Another work uses a network of rain gauge data for *short-term* prediction of urban pluvial floods. The data archive available is comparable to that available for the CCDW. The rainfall rate was collected every 30 minutes from June 6, 2006 and December 19, 2010. This work, by Maureen Coat, primarily focuses on the interpolation of the 88 point measurements (rain gauge stations) to create a continuous precipitation rate mapping. A few of the most common interpolation techniques were mentioned, such as the Inverse Distance Weight, Liska's Method, and the Polygon of Thiessen. The authors decided to use another, more efficient, technique called the Kriging method, which is statistically designed for geophysical variables with a continuous distribution. The authors describe that future work would compare the results of the Kriging method with radar imagery although admitting radar imagery is notorious for its own sources of error. The figure below illustrates how the Kriging method is used to create continuous radar imagery from point measurements.



Fig. 2. Kriging method overlay

IV. Preliminary VTB Results

Two types of data were collected for this study, radar reflectivity (dBZ) data and tipping bucket precipitation rate (mm/hr). The time series was from April 1, 2007 to November 30, 2007 and was formatted to 15-min resolution, for a total of ~17,500 data points. The radar uses was from Davenport, IA (KDVN) and the tipping bucket targeted was in Oxford, IA, some 120 km away.

Of the original data set, 2000 points were chosen randomly for modeling. Seventy percent of this new data set was randomly assigned to the training set and the remaining 30% was assigned to the testing set. The preliminary results of the NN testing are shown in the figure below.



Fig. 3. Preliminary VTB results

Below are the mean absolute error (MAE) for the entire data set, and also only considering rain events.

Total MAE (mm/hr)	Rain event MAE (mm/hr)
0.16	0.21

The preliminary model shows that it is capable of modeling precipitation rate at the tipping bucket based on radar reflectivity, and the model took less than one minute to build. Techniques to enhance the model's accuracy in future work will be used, such as trying different activation functions, NN structures, and using feature selection algorithms to ensure that only those parameters that improve the model are used.

V. IPWRSM Inspired Future Research Directions

The interaction between universities made on the 2010 IPWRSM course was inductive to new ideas, and the connections paved the way for some possible collaborative studies between the participating colleges. Some research topics that were spawned from the intercontinental brainstorming are presented below.

5.1. Hysteresis: looped rating curve analysis

Hysteresis can be described with the following. For a given stage height, discharge values are greater for rising water levels than for receding water levels. Hysteresis is the lag between peaks in discharge (antecedent) and peaks in stage height (consequent). Figure 2 displays the looped rating curve on discharge vs stage height axis.



Fig. 4. The looped rating curve

Following Professor Solomatine's work with his discharge-stage relationship analysis, future studies in Clear Creek may involve using clustering techniques and time series data mining to better model the hysteresis of discharge at the three gauging stations in the basin. If patterns in clusters of memory parameters (t-1T, t-2T, etc., where T is a time inteval) could be found, then a better description of the looped rating curve could be provided, and thus discharge could be more accurately modeled.

5.2. VTB vs. Kriging Method

The VTB, as developed in this paper, could be compared with a Kriging method interpolation of the three tipping buckets, as suggested discussed at the Imperial College in London. It would be interesting to see the agreement between the Kriging method's precipitation mapping versus the VTB's mapping. Perhaps, the Kriging Method

could even be used as an additional input parameter for the VTB. In this case the VTB would consider both the reflectivity and its Kriging method precipitation interpolation value for its prediction.

5.3. VTB-SWAT integration

The ultimate motivation for building a mapping of VTBs is to be implemented in a calibration based model, the SWAT model. The SWAT model currently uses the data from the three tipping buckets, oriented roughly West-East spaced out 12km form one another for its hydrological calculations. As discussed earlier, a 1km by 1km VTB spatial resolution would be a great improvement to the basin, and raise the number of precipitation measurements from 3, to ~200, and the frequency of measurement would increase from 4/hr to 12/hr. This improvement in detail to the precipitation data will surely enhance the SWAT models hydrological modeling capability.

VI. Conclusion

The University of Iowa's 2010 International Perspectives in Water Resource Science and Management: The Netherlands, UK was a rare opportunity for engineers to meet to discuss tools, research ideas, and share experiences at an international level. The transfer of knowledge, information, and personal expertise will prove to be invaluable to all universities that participated.

In this paper the role of data mining in hydrology, known as the field of hydroinformatics, is discussed as a support for physics based models. Data mining applications in hydrology are mentioned both from the literature and the personal research of international colleagues. The motivation for a system of VTBs is supported from the studies of those at the universities that were visited, and their discussion of the need for high resolution radar data for better hydrological modeling. Finally, an initial prototype model is developed for the VTB with results disclosed. Future research directions such as looped rating curve analysis, comparison of the VTB system with the Kriging precipitation interpolation method, and also the integration of the VTB system with the SWAT model.

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Review of Hydraulic Flood Modeling Software used in Belgium, The Netherlands, and The United Kingdom



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August 15th, 2010

International Perspectives in Water Resource Management IIHR – Hydroscience & Engineering University of Iowa, College of Engineering

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1. INTRODUCTION

The movement of flood waters through the landscape can be approximated using many different methods. Describing natural physical phenomena using numerical methods requires making broad assumptions to develop governing equations. While simple hydraulic modeling methods may be sufficient for approximating propagation of flood peaks through river channels, more complex hydraulic analyses may be necessary to incorporate effects of infrastructure or complex overland flow. Advanced models are capable of modeling more detailed physical phenomena, but this does not correspond to a decrease in uncertainty.

During May of 2010, researchers from the University of Iowa visited Belgium, the Netherlands, England and Wales as part of the International Perspectives in Water Resources Science and Management course. These destination countries were selected based on their historic flood protection efforts and their –Living with Floods" mitigation philosophy. The theme of the course, –Living with Floods" was especially appropriate given that many students taking the course were conducting research for the recently established Iowa Flood Center. The Iowa Flood Center (IFC) was created with the mission to perform advanced research and education about floods.

IFC shared similar research interests and mission statements as many of the organizations visited during the course. These entities gather real-time hydrologic data within their respective regions in order to evaluate flood risk. Hydrologic data are used to produce a variety of forecast products using the latest numerical modeling and data assimilation techniques. A vital component of these entities' flood forecasting efforts is to effectively communicate numerical simulation results and corresponding flood risk to the general public. IFC was in the early stages of developing a flood forecasting framework, hence, visiting established forecasting

centers provided many opportunities to discuss and observe different approaches to flood mitigation.

Hydraulic modeling is an important element of establishing a robust flood forecasting framework. Simulation results from hydraulic models can be used to produce inundation maps that community officials or the general public can use to evaluate their flood risk. This paper discusses general hydraulic modeling approaches and a review of software used by different organizations in Europe to issue flood forecasts.

2. LITERATURE REVIEW

2.1. Unsteady flow routing

At the core of all unsteady flow routing computer simulations are the Navier-Stokes equations for an incompressible fluid. These fundamental fluid mechanics equations are derived using continuity given in Equation 2.1.

$$\frac{\partial p}{\partial t} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$
(2.1)

Using the differential equations of motion and continuity, the Navier-Stokes equations of fluid motion are developed, as shown in Equations 2.2 to 2.4.

$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) = -\frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) + \rho g_x \qquad (2.2)$$

$$\rho\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}\right) = -\frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right) + \rho g_y \qquad (2.3)$$

$$\rho\left(\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\right) = -\frac{\partial p}{\partial z} + \mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) + \rho g_z \qquad (2.4)$$

Where ρ is fluid density, *x*, *y*, and *z* are Cartesian coordinates, *t* is time, *u*, *v*, and *w* are velocity components in the *x*, *y*, and *z* directions, respectively, *p* is pressure, μ is viscosity, and *g* is gravitational acceleration. While these governing equations are applicable in almost all situations, computational constraints typically dictate the degree of simulation detail achieved. Three-dimensional (3D) hydrodynamic modeling at the reach scale is typically unjustifiable when parameters of interest (velocity direction and magnitude, inundation extent, and water

depth) can be predicted using one-dimensional (1D) or two-dimensional (2D) computational fluid dynamics (CFD) (Bates and De Roo 2000; Piotrowski 2010).

2.1.1. One-dimensional numerical models

The most widely used approach to modeling fluvial hydraulics has been 1D finite difference solutions of the full Saint-Venant Equations (Bates and De Roo 2000). The Saint-Venant Equations are based on conservation equations of mass and momentum for a control volume, as shown in differential form in Equations 2.5 and 2.6.

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \tag{2.5}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} (uQ) + gA \left(\frac{\partial h}{\partial x} - S_0 \right) + gAS_f = 0$$
(2.6)

Where Q is discharge, A is cross-sectional flow area, u is longitudinal flow velocity, h is flow depth, S_o is bed slope, and S_f is friction slope. 1D solutions of the full Saint-Venant Equations are derived based on several assumptions: the flow is one-dimensional, the water level across the section is horizontal, the streamline curvature is small and vertical accelerations are negligible, the effects of boundary friction and turbulence can be accounted for using resistance laws analogous to those for steady flow conditions, and the average channel bed slope is small so the cosine of the angle can be replaced by unity (Cunge, Holly and Verwey 1980).

Widely available software such as MIKE11 and HEC-RAS use the general form of the section-averaged Navier-Stokes equations. The basic forms of the equations used in MIKE11 are shown in Equations 2.7 and 2.8.
$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \tag{2.7}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial \left(\alpha \frac{Q^2}{A}\right)}{\partial x} + gA \frac{\partial h}{\partial x} + \frac{gQ|Q|}{C^2AR} = 0$$
(2.8)

Where Q is discharge, x is longitudinal channel distance, A is cross-sectional area, q is lateral inflow, t is time, h is flow depth, C is the Chezy coefficient and R is the hydraulic radius.

An inherent assumption of 1D finite difference river modeling is that flow velocities are perpendicular to cross-sections. Additionally, water surface elevations are assumed constant for entire cross-sections. For river reaches containing backwater areas or naturally occurring diversion channels, these assumptions are frequently violated. For out-of-bank flow, interaction with the floodplain results in highly complex fluid movement with at least two-dimensional properties. Flow at the channel-floodplain transition has been shown to develop a three-dimensional flow field due to intense shear layers (Bates and De Roo 2000).

Development of a one-dimensional hydraulic model requires user discretion in defining model geometry. Bates and De Roo (2000) found that subjectivity of cross-section placement is an important contributor to the overall accuracy of a 1D hydraulic model. In addition to directly determining overbank reach lengths, placement of cross-sections must be executed so that changes in conveyance due to expansions or contractions are accurately captured.

2.1.2. Two-dimensional numerical models

Complex interaction of channel and floodplain flow fields make two-dimensional simulation codes more desirable than one-dimensional codes in many modeling situations

(Horritt and Bates 2002). Continual improvements in computational resources and affordability have also increased implementation of two-dimensional modeling. Most widely used commercial two-dimensional codes utilize depth-averaged Navier-Stokes equations, commonly called the Saint-Venant shallow water equations, shown in Equations 2.9 to 2.11.

$$\frac{\partial h}{\partial t} + \frac{\partial (hU)}{\partial x} + \frac{\partial (hV)}{\partial y} = 0$$
(2.9)

$$\frac{\partial(hU)}{\partial t} + \frac{\partial(hUU)}{\partial x} + \frac{\partial(VU)}{\partial y} = \frac{\partial(hT_{xx})}{\partial x} + \frac{\partial(hT_{xy})}{\partial y} - gh\frac{\partial z}{\partial x} - \frac{\tau_{bx}}{\rho}$$
(2.10)

$$\frac{\partial(hV)}{\partial t} + \frac{\partial(hUV)}{\partial x} + \frac{\partial(VV)}{\partial y} = \frac{\partial(hT_{xy})}{\partial x} + \frac{\partial(hT_{yy})}{\partial y} - gh\frac{\partial z}{\partial y} - \frac{\tau_{by}}{\rho}$$
(2.11)

Where h is flow depth, U and V are velocities in the x and y directions, T_{xx} , T_{xy} , and T_{yy} are depth-averaged turbulent stresses, z is the water surface elevation, and τ_{bx} , τ_{by} are bed shear stresses.

2.1.3. Coupling of 1D/2D numerical models

Modeling of urban flooding has presented several challenges to using typical one- and two- dimensional numerical codes (Patro, et al. 2009). One-dimensional numerical models are unable to resolve complex floodplain flow fields and require post-processing to produce realistic flood extents. Two-dimensional numerical models are unable to model structural elements that may produce super-critical or pressurized flow conditions. Consequently, recent urban flood modeling efforts have been focused on dynamically coupling one- and two-dimensional models to avoid these limitations (Frank, et al. 2001; Patro, et al. 2009). A one-dimensional numerical model of the river channel complimented by a two-dimensional model of the floodplain provides improvements in hydraulic modeling accuracy and computational efficiency. If an entire river reach is modeled using a one-dimensional model, then computational nodes within that portion of the two-dimensional mesh will not become active, improving computational efficiency. Several hydraulic models have successfully been coupled or are available in commercial packages: Lin et al. (2006) coupled ISIS and DIVAST, Delft-FLS, LISFLOOD-FP, SOBEK 1D2D and MIKE FLOOD.

Flanders Hydraulics Research in Antwerp, Belgium is responsible for monitoring the water levels on the waterways and canals in Flanders, the Flemish speaking region of Belgium. Forecasts are reported on the website the organization's flood forecast website (www.waterstanden.be). Hydraulic analyses are performed using MIKE FLOOD, a product of the Danish Hydraulics Institute (DHI). MIKE FLOOD has been developed to accommodate several types of links between one-dimensional MIKE 11 and two-dimensional MIKE 21

These include the standard link, lateral link, and structure link as shown in Figure 1. Standard links are explicit and are able to link ends of a MIKE 11 branch with a MIKE 21 computational mesh. These types of links allow model boundary conditions to be controlled by a rating curve, which is useful when modeling unsteady conditions. The discharge contribution from a MIKE 11 branch affects the continuity and momentum equations in the MIKE 21 cell when linked with a standard link (DHI 2009). The link requires the MIKE 11 branch be one time step behind the MIKE21 mesh; therefore a discharge predictor is utilized for the time step n + 1/2, as shown in Equation 2.12.

$$\frac{\partial Q^{n+1/2}}{\partial t} = -\left(gA\frac{\partial H^n}{\partial x} + \frac{Q^n |Q^n|}{AC^2 R}\right)$$
(2.12)

Where Q is discharge, t is time, g is acceleration of gravity, A is cross-sectional area, H is water level, x is longitudinal distance, C is the Chezy coefficient, and R is hydraulic radius. This predictor assumes that the roughness coefficient is controlling the flow.

Lateral linking of a MIKE 11 branch to a MIKE 21 mesh allows water to enter the floodplain laterally from the river channel. The linking method is explicit. The flow exchanged between the two models is controlled by a structural relationship such as a weir equation. Since one-dimensional hydraulic models like MIKE 11 do not consider cross-channel flow, momentum cannot be conserved across this type of link (DHI 2009).

Structural links are used to incorporate the effects of structural elements such as dams and bridges. This linking procedure is the most stable coupling method due to its implicit nature. The function of the link is to utilize the momentum calculated through a MIKE 11 branch to modify the momentum in adjacent MIKE 21 cells in order to represent the hydraulic effects of the structure (DHI 2009). Conservation of momentum is not guaranteed, so emphasis is placed on interrogating simulation results.



Figure 1. MIKE FLOOD allows coupling of 1D hydraulic models to a 2D computation mesh using standard, lateral, and structure links.

Two packages of modeling software of interest are produced by Deltares, headquartered in Delft, the Netherlands. A coupled 2D/3D model, Delft3D, can be used for investigating, hydrodynamics, sediment transport, morphology, and water quality. Deltares other software, SOBEK, is more similar to that used by the IFC. SOBEK uses a coupled 1D/2D solver and is a powerful for flood forecasting. There are several modules of SOBEK available, SOBEK-Rural, SOBEK-Urban, and SOBEK-River. The River module is entirely 1-dimensional and can solve for water quality, morphology and sediment transport. Both the Rural and Urban modules link the 1DFLOW element to the 2D Overland Flow Module, however only the Rural module contains a water quality solver. From Dhondia and Stelling (2002), the interaction between the 1D and 2D solvers is determined by Equation 2.13.

$$\frac{dV_{i,j}(\zeta)}{dt} + \Delta y((uh)_{i,j} - (uh)_{i-1,j}) + \Delta x((vh)_{i,j} - (vh)_{i,j-1}) + \sum_{l=K_{i,j}^{1}}^{l=K_{i,j}^{L,i,j}} (Q_n) = 0$$
(2.13)

Where V is the combined 1D/2D volume, u is the velocity in the x direction, v is the velocity in the y direction, h is the total water height above the 2D bottom, ζ is the water level, Δx is the grid size in the x direction, Δy is the grid size in the y direction, and Q_n is the discharge in the direction normal to the mass volume faces.

The research group lead by University of Bristol Professor Paul Bates has been developing LISFLOOD-FP, a flood simulation software package for research. LISFLOOD-FP assumes a rectangular stream channel of fixed width. The model uses the 1D St. Venant equations until the channel depth is exceeded, and then the 2D inundation extent is estimated using Manning's equation and a storage cell concept applied over a raster DEM. The model has been improved since the original version was first created by Bates and Paul De Roo in 2001. OpenMP support was added to allow parallelization, increasing computation time (Neal et al, 2009). An inertial element was added to account for the mass of the water (Bates et al. 2010). This reduced oscillations from cell to cell during the simulation. The resulting improvement in stability allowed for great reductions in time step, and reductions in computation times of over 100 times that of the non-inertial formulation.

Course participants visited two English engineering companies, Halcrow and HR Wallingford. Halcrow produces the hydraulic analysis software package ISIS. A branch of HR Wallingford, Wallingford Software, produced its own flood forecasting package, Infoworks. Infoworks uses the same solver as ISIS. Recently, Wallingford Software was sold to MWH Soft, and HR Wallingford no longer produces its own commercial software. ISIS 1D is the onedimensional component of the software, and can be linked to either ISIS 2D or TUFLOW, a product of WBM, to solve for the two-dimensional overland flow. The solver is based on the DIVAST (Depth integrated Velocities and Solute Transport) numerical engine, research project completed by Professors Roger Falconer and Binliang Lin of Cardiff University, another site visited during the course. ISIS, like all of the previous software mentioned, uses the St. Venant equations to solve for the fluid flow.

2.2. Sources of Error

Inundation maps are the most useful results produced from flood simulations, but uncertainties must be considered because error is introduced throughout the development process. Currently, uncertainties are typically left unspecified when flood inundation maps are released (Bales and Wagner 2009). The cumulative effect of uncertainties introduced during data collection, model development, numerical simulation, post-processing, and theoretical assumptions can render results inaccurate and ultimately misleading.

Model roughness parameters and geometry are considered to be the most important factors in predicting inundation extent. Common modeling practice includes parameterizing roughness coefficients to calibrate to observed measurements while minimizing error between the observation and prediction (Aronica, Hankin and Beven 1998). This approach assumes that there is one optimum set of parameters to minimize this error; however, the non-linearity of flood models likely indicates the existence of several optimum parameter sets (Aronica, Hankin and Beven 1998). One method to determine these optimum parameter sets is to perform Monte-Carlo simulations while utilizing the generalized likelihood uncertainty estimation (GLUE) procedure (Aronica, Hankin and Beven 1998) (Pappenberger, Beven, et al. 2004).

One of the most important data sources in the development of flood inundation models is topography. Currently, the highest resolution topographic data available is Light Detection and Ranging (LiDAR) derived, which typically has a horizontal resolution of 1m and vertical accuracy of ± 15 cm (Mason, et al. 2003). These datasets mark a significant improvement over the USGS National Elevation Dataset 1/3 Arc Second DEMs, which have a resolution of approximately 10 m and vertical accuracy of approximately ± 7 m (USGS 2008). Werner (2001) investigated the impact of DEM grid size on flood extent mapping when intersecting a water surface result from a 1D hydraulic simulation of 50 and 200 year floods in a study reach. The approach was to create DEMs with resolutions of 2.5, 5, 10, and 25 meters, and compare inundated area at different depths and total inundation area for a test reach. They found that inundation area increased 10% when DEM resolution increased from 5 m to 25 m during the 50 year event and 26% when DEM resolution swould vary by river reach. For example, a channelized reach would demonstrate less grid sensitivity than one with a wide floodplain.

Inundation maps are typically created with a steady gradually varied flow assumption. The largest implication of this assumption is that the inundation area is over- predicted at higher discharges due to the time required to reach a steady condition. This time typically exceeds the duration and total volume of the peak discharge present in a flood hydrograph (Bales and Wagner 2009). A hydrograph that rises slowly would result in more inundation than a flash flood hydrograph. An alternative to developing inundation maps with a steady flow assumption is to utilize real-time forecasting to estimate inundation. This approach would incorporate the effects of hysteresis in the delineation of flood extent (Bales and Wagner 2009). A significant

challenge in developing this framework is constructing hydraulic models capable of running faster than a 1:1 ratio of simulation time to real time.

Disclosure of uncertainty along with inundation boundaries in mapping products would more clearly communicate flood risk. Smemoe, et al. (2007) developed a framework for evaluation and presentation of floodplain uncertainty maps. They created maps by running a hydrologic, hydraulic, and flood plain delineation model. Models were run repeatedly using stochastic probability distribution function values as input parameters, generating a series of flood boundaries. These boundaries were used to create a continuous inundation map showing uncertainties from 0 to 100 percent for a 100 year event.

3. CONCLUSIONS

The International Perspectives in Water Resources Science and Management course provided opportunities to gain valuable insight into existing flood forecasting systems in Europe. Students were able to observe the unique challenges faced by communities living in these flood prone areas. The course was especially valuable for those students who are involved with the Iowa Flood Center. An important component of any flood investigation is the software used for hydraulic analysis. There are a number of European software packages available, whether for commercial or non-commercial use. Examples of the applicability of various numerical modeling methods were presented by several research groups and operational flood forecasting centers. Selecting an appropriate modeling package depends on the degree of detail desired and software limitations.

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Flood Risk Management

Kyutae Lee, 2010



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1. Background

1.1 European Experiences as a Pioneer in Flood Risk Management

Between 1998 and 2004, Europe suffered over 100 major damaging floods, including the catastrophic floods along the Danube and Elbe rivers in summer 2002. Severe floods in 2005 further reinforced the need for concerted action. Since 1998 floods in Europe have caused some 700 deaths, the displacement of about half a million people and at least \in 25 billion in insured economic losses.

In 2000, the Water Framework Directive (more formally the Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy) was initiated as a European Union directive which commits European Union member states to achieve good qualitative and quantitative status of all water bodies (including marine waters up to kilometer from shore) by 2015. It is a framework in the sense that it prescribes steps to reach the common goal rather than adopting the more traditional limit value approach (Wikepedia, 2010).

In addition, the Directive 2007/60/EC was proposed by the European Commission on 18/01/2006, and was finally published in the Official Journal on 6 November 2007. Its aim is to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activity. The Directive requires Member States to first carry out a preliminary assessment by 2011 to identify the river basins and associated coastal areas at risk of flooding. For such zones they would then need to draw up flood risk maps by 2013 and establish flood risk management plans focused on prevention, protection and preparedness by 2015. The Directive applies to inland waters as well as all coastal waters across the whole territory of the EU (European Commission Environment, 2010).

In April 2007, the Parliament and Council of the European Union agreed the wording on a new European Directive on the assessment and management of flood risks. The Integrated Project FLOODsite is listed as one of the European actions which support the Directive. FLOODsite is active in stimulating the uptake of research advances through guidance for professionals, public information and educational material. FLOODsite is an "Integrated Project" in the Global

Change and Ecosystems priority of the Sixth Framework Programme of the European Commission. It commenced in 2004 and runs to 2009. The FLOODsite consortium includes 37 of Europe''s leading institutes and universities and the project involves managers, researchers and practitioners from a range of government, commercial and research organizations, specializing in aspects of flood risk management (PEGASO, 2008). Most of the valuable information herein is attributed to the projects and papers which FLOODsite researches are involved.

1.2 What is flood risk management?

Flood events are part of nature. It is neither technically feasible nor economically affordable to prevent all properties from flooding. Then, what could be the best strategy to minimize the harm from the flood? In recent years, a paradigm shift on flood policy is recognized from the old concept of "flood protection" to "flood risk management" (Schanze 2006). "Flood protection" aims at preventing flood hazards up to a certain magnitude by providing a certain protection level (e.g. against floods of an exceedance probability once in 100 years). Such protection levels are mostly established by means of flood defense structures such as dikes, dunes, etc. Hereby we need to clearly define the concept of "*flood risk*" for comparison. The term *flood risk* is the product of the likelihood or chance of flooding, multiplied by the consequences or impacts of flooding (See e.g. Knight 1921, Gouldby & Samuels 2005, Environment Agency Wales 2010), i.e.,

Flood risk = likelihood (chance) of flooding × the consequences (impacts) of flooding => Annual Average Damage (AAD)

In other words, this is *the expected annual average negative consequence of flooding* (Annual Average Damage (AAD)), whereas negative "consequences" covers **economic, social** as well as **environmental** consequences (Meyer, 2007). It tries to adjust flood protection to the risk situation by concentrating protection efforts to areas with a high expected damage, in order to spend public funds in an economically efficient way (Messner & Meyer, 2006). Therefore a risk-based approach is to achieve the best management results possible using the budget and resources available.

In more detail, the likelihood (or chance) of flooding occurring in any one year can be expressed as a probability or an annual chance; for example, a 1% annual probability of flooding or 1 in 100 chance of flooding at a location in any year, while the consequences (or impacts) of flooding can have serious effects not only on people and property, but also on essential services, infrastructure and the environment. The Pitt Review (Pitt, 2008) into the 2007 floods in UK highlighted the significance of the impacts of flooding on health. This included the stress caused by being flooded; the loss of irreplaceable personal items; the length of time before people can return to their homes; and the huge cost to people if they are inadequately insured.

Flood risk management can be broadly divided in two steps (Schanze 2006): *flood risk assessment* and *flood risk reduction*. *Flood risk analysis and assessment* are often called as a *flood risk assessment* without separation. While the objective of *flood risk assessment* is to provide information on current or future flood risks in order to find out where these risk are unacceptably high, *risk reduction* aims at finding measures to decrease these risks. The Figure 1 below shows the schematic diagram of flood risk management. It is important to note that hazard determination is the step associated with the determination of likelihood of flooding and inundation characteristics, and therefore assessing and mapping flood risk map is the necessary step at this stage. This will further be discussed at Section 2.3, "damage evaluation –necessary information for flood damage evaluation".



Figure 1. A diagram of flood risk management scheme (Modified from Schanze (2006)) **1.3 Strategies in Managing Flood Risk**

A risk management approach requires a mix of actions to manage **both the likelihood and consequences of flooding**. The historic approach has mainly focused on defenses and managing the likelihood of flooding. Going forward the balance of investment needs to be considered and even more focus given to actions to manage the consequences as well. For example, the removal of existing properties from flood risk areas, directing new development away from flood risk areas or the construction of flood defenses all **reduce the likelihood of flooding**. Actions to raise flood awareness, to provide timely flood warnings, or to make individual properties more resilient to flooding, **reduce the consequences of flooding** (Environment Agency Wales, 2010). The followings below show the details.

Some of the wider range of actions that could help to manage <u>the consequences of flooding</u> include:

- increased coverage and improved flood warning;
- increased awareness to enable property owners to take action before flooding occurs to reduce their damages;
- increased awareness amongst the owners of essential services and infrastructure to enable them to plan for and manage their flood risk;
- increased resistance of new and existing property to flooding, for example installing flood gates or covers for air-brick vents;
- increased resilience of new and existing property to flooding, for example, raising electrical sockets, using lime-free plaster and tiled or stone surfaces and floors to reduce the time after flooding before the property is habitable or usable.

The wider range of actions could also include changes in **land use or land management** to reduce <u>the likelihood of flooding</u>.

- restoring currently defended floodplains to increase the capacity for storage of flood flows and to reduce the flood risk downstream;
- removing artificial land drainage and restoring more natural and slower rates of surface run-off;
- using tree planting and shelter belts to reduce surface run-off;
- encouraging and supporting good soil management reducing soil compaction and therefore surface water run-off;
- using sustainable urban drainage systems to reduce the rates of run-off.

The most appropriate balance of flood risk management actions will vary between locations and communities. <u>Choices will need to be made about how and where investment in managing flood</u> <u>risk is best directed</u>. The Section 2.2 below briefly presents an example showing the determination of where to invest. Communities and those directly affected should be involved in this debate.

1.4 Difference between Flood Map and Flood Risk Map?

To prevent confusion, we need to clarify at this point the difference **between flood map and flood risk map**. They both involve modeling the behavior of the sea and river basins in different weather and tidal conditions, and matching this to knowledge of land topography to see where floods are likely to arise and how often. However, these two mapping approach can be differentiated as followings (Environment Agency Wales, 2010):

• The Flood Map is <u>for use by property owners and Local Authorities</u> and shows where floods may occur and how severe they could be. It is a map of the natural floodplain showing areas that could flood if **no defense structures** were in place. It helps property owners recognize risks and prepare for floods.

• The Flood Risk Map differs from the flood map because it considers the impact of flood defense structures and other measures that reduce risk. Its purpose is contribute to <u>flood risk</u> management policy and investment priorities for government, and to help insurance industry in setting risk-based premiums and excesses as well as to people for raising awareness and preparedness on individual flood risk.

2. Methodology for Risk Assessment and Reduction

2.1 Quantifying Flood Risk – Annual Average Damages (AAD)

Flood risk is generally quantified in monetary terms as Annual Average Damages (AAD). This has units of "money/year" and is a function of both the likelihood and consequences of flooding. Annual Average Damages take account of a wide range of floods, from the relatively frequent, to rare and more severe incidents. Rare incidents have a low likelihood but may have high consequences and may therefore be a significant risk. The full cost of flooding from all sources is, however, significantly higher. This is partly due to neglecting the wider impacts on society and business, such as loss of essential services, transport delays, disruption to businesses and impacts on agriculture and the environment which are not included in the general calculation of AAD. From the risk assessment perspective, the negative consequences have to be evaluated for flood events of different probability in order to construct a damage-probability curve (see Figure 2). The risk (or AAD) is shown by the area or the integral under the curve (see Figure 3).



Figure 2. Damage-probability curve: a) and b) procedure of flood risk calculation; c) and d) evaluation of measures by cost-benefit analysis: risk reduction=benefit (adapted from Meyer, 2007)



Figure 3. Calculation of Annual Average Damage (AAD) (adapted from Meyer, 2007)

The AAD can be calculated according to the formula presented in Figure 3. That is, the variable \overline{D} is calculated by summing up several small rectangles which are risk or AAD.

2.2 Deciding where to invest - flood risk management benefits

(This chapter is excerpted from Environment Agency Wales, 2010)

The benefit from a flood risk management intervention is measured by the flood damages avoided. This can be quantified in monetary terms, and public money is invested to reduce flood damages. This investment is economically justified if the amount of "benefit" (or damages avoided, calculated from the AAD) exceeds the amount invested (or the "cost").

So, for example:

- if £0.6 million is spent on flood defenses to reduce <u>the likelihood of flooding</u> to a group of properties, and the total flood damages avoided (benefit) over the life of these defenses is, say, £1 million, then;
- the net benefit of this investment (benefits $-\cos t$) is £1m $\pm 0.6m = \pm 0.4m$, and;
- the benefit cost ratio for this investment (benefits/cost) is $\pounds 1m/\pounds 0.6m = 1.7$
- •the positive net benefit and a benefit cost ratio greater than 1 demonstrate this is an economically justified investment.

Alternatively the £0.6m from the earlier example, could be invested in actions to manage <u>the</u> <u>consequences of flooding, rather than the likelihood</u>. This could involve works to the properties, to either prevent flood water entering, or to enable the properties to be habitable more quickly after flooding occurs, such as raising the electrical sockets above flood levels and the use of tiled or stone surfaces which are less susceptible to flood damage and quicker to clean up after a flood. The £0.6m could be used to provide timely flood warnings. These reduce the risk to life and property by giving people and the emergency services advance warning, thereby enabling them to take action to reduce the consequences of flooding. Provided the benefits of these actions exceed the costs, these would be economically justified investments.

If the £0.6m could be used to purchase the properties at flood risk and relocate the residents to equivalent properties outside of the flood risk area, this could also be an economically justified investment option. This option would remove the flood risk completely.

2.3 Flood Damage evaluation

2.3.1 Necessary Information for flood damage evaluation

Damage evaluation approaches usually deploy the following kind of input data in order to estimate flood damage (Messner et al. 2007):

- Inundation characteristics, i.e. data especially on the estimated area and depth of a certain flood event, calculated by hydrodynamic models.
- Information on number and type of the exposed elements at risk (people, properties, biotopes etc.), usually gathered from land use data sources.
- Information about the value of these elements at risk (either in monetary or non-monetary terms).
- Information about the susceptibility of these elements at risk, usually expressed by depth/damage-relationships (Depth/damage functions).



Figure 4. Damage evaluation – necessary information (Adapted from Meyer, 2007)

Apart from these general components, a huge variety of damage evaluation approaches exist. Regarding their spatial scale and accuracy level, the existing methods can be broadly differentiated into **macro-, meso- and micro-scale** approaches. Macro scale approaches e.g. often rely on land use information with a low spatial resolution and/or low typological differentiation in order to reduce the effort of analysis and hence be able to consider large river basins as a whole (see e.g. IKSR 2001, Sayers et al. 2002). Micro-scale approaches on the other side try to achieve more accurate results by applying very detailed land use data, as well as value and susceptibility information (see e.g. Penning-Rowsell et al. 2003). Of course this requires more effort which restricts these approaches often to small research areas.

2.3.2 Damage evaluation methods in Europe

Even though Damage evaluation methods all have similar data requirements as described in Figure 4, a great variety of methods exists in practice. In this sub-chapter, existing damage evaluation approaches applied in England, the Netherlands, the Czech Republic and Germany were analyzed. The objective of the study was to describe different methods, to compare the different approaches but also to unveil deficits in current practice (Meyer & Messner, 2006).

England

- Hierarchical system of damage evaluation methods for national, regional and local scale
- Damages on assets, but also social and environmental losses are considered
- A standardised set of absolute damage functions is the basis for damage evaluation on all levels
- Object-oriented land use information is gathered by field surveys (micro level) or obatined from a national property dataset (meso-macro level)

Netherlands

- · One standard method has been developed
- Mainly monetary economic damages are considered
- A set of 11 relative damage functions is used
- A mix of different land use data sources is used (official & commercial data sources)
- Standardised maximum damages are derived from official statistics

Czech Republic

- 3 methods for national, regional & local scale
- Focus on monetary economic damages
- Up to 300 relative damage functions for building subtypes
- A combination of aggregated and object-oriented land use data sources is used
- Value of assets are calculated by construction costs
 per cubic metre

Germany

- Different methods in each federal state
- Focus on monetary economic damages
- Absolute as well as relative damage functions are used (main source: HOWAS database)
- Land use data is either obtained from field surveys or from secondary sources
- Value of assets: Varies from object assessment, official statistics to standardised values

Figure 5. Diverse national damage evaluation approaches

Scale	Example		Land use data	Determination of values of assets	Damage functions
macro	1	Rhine atlas (IKSR 2001)	aggregated data (Corine Land Cover)	approximate values for each land use category	relative
	2	National appraisal of assets at risk (NAAR, UK) (DEFRA 2001)	object oriented data (National property dataset)	approximate valuation of assets	Weighted Annual Average Damages
	3	RASP High level methodology (Sayers et al. 2002)	object oriented data (National property dataset)		absolute
meso	1	German meso-scale approach (Colijn et al. 2000; MURL 2000, etc.)	aggregated data (ATKIS-DLM)	aggregated data from official statistics disaggregation to land use units	relative
	2	Dutch Standard Method (Kok et al. 2004)	 aggregated data geomarketing data 	 approximate values per unit of each damage category calculated from official statistics 	relative
	3	MDSF (UK) (DEFRA et al. 2004)	object oriented data (National property dataset)	-	absolute
	4	DWA-approach (Germany)	object oriented data (cadastral data)	-	absolute, region-specific
micro	1	MERK, German Coast (Sterr et al. 2005)	object oriented data (field surveys)	official building assessment guidelines	relative
	2	Multi Coloured Manual, UK (Penning-Rowsell et al. 2003)	object oriented data (field surveys)	1	absolute
	3	Czech method 3 (Čihák et al. 2005)	object oriented data (field surveys, address- point data, cadastral maps, also aggregated data)	values on building components from official statistics	relative
	4	DWA-approach (Germany)	object oriented data (field surveys)	1	absolute, region-specific

(Adapted from the Symposium poster of Meyer & Messner, 2006)

Table 1. Overview of the typical, exemplary approaches (Adapted from Meyer et. al, 2009)

Figure 5 above shows very similar characteristics among countries, but they are slightly different with respect to the detail methods and sources they are using. In addition, Table 1 above presents different kinds of method which are currently being used in European countries depending on different spatial scales.

The main common deficits found in four European countries" approaches are as follows:

- Social and environmental effects of floods are rarely considered.
- Uncertainties in the results are usually not documented.
- Sometimes full replacement costs are used to estimate flood damages, not depreciated values (overestimation of flood damages).
- Lack in transboundary co-operation: different approaches in one river basin.

These common problems will be more discussed in Section 3.

2.3.3 Different types of flood damages

Different types of flood damages can be classified as presented in Table 2. As stated earlier in Section 1.2, damages can be classified as economic, social, and environmental damages. Economic damages such as buildings, contents, etc which is tangible and direct can be easily estimated using AAD concepts described in Section 2.1, however; social and environmental damages are usually considered as tangible indirect, intangible direct, or intangible indirect damages and they are not easy to estimate. The detailed methods for these three damage categories have been reviewed and reported in Floodsite project report: T09-07-03 by Meyer et.al, 2009. For the simplification, this paper will only present basic implementation steps of direct and tangible damage evaluation in the next Section, however; recently developed alternative method, called *multicriteria analysis* (MCA) will be introduced instead. The MCA method is an appropriate method of incorporating all relevant types of consequences without measuring them on one monetary scale.

		Measurement		
		Tangible	Intangible	
Form of	Direct	Physical damage to assets: - Buildings - Contents - Infrastructure	 Loss of life Health effects Loss of ecological goods 	
oamage	Indirect	Loss of industrial production Traffic disruption Emergency costs	Inconvenience of post-flood recovery Increased vulnerability of survivors	

Table 2. Typology of flood damages with examples (Adapted from Meyer et. al, 2009)

2.3.4 Basic implementation steps of direct, tangible damage evaluation

Figure 6 briefly shows the schematic diagram of direct, tangible damage evaluation, and the below of this figure explains a little bit details of these procedures.

Once we finished the calculation of the expected damages at the step4, then that means we are now ready to proceed to the next stage, which is risk reduction strategies. It is very important to note this. For example, we have to compare the current risks based on each flooding scenarios with several alternatives when we plan to build new structural or non-structural measures to reduce flood risk. Therefore, damage evaluation steps described below are purely to present the risks on each flooding scenario. In order to build an appropriate flood risk reduction plan, one always should be done by means of cost-benefit analysis. The investment scenario modeling based on cost-benefit analysis will be introduced as an example in Section 4.1, and alternative method, MCA to account for all kinds of flood consequences as mentioned above will be presented in Section 4.2.



Figure 6. Basic steps of direct, tangible damage evaluation (Adapted from Meyer et. al, 2009)

Step1: For the choice of an appropriate method of damage evaluation the following questions are crucial:

- Spatial scale: Which spatial level is planned to be considered? Is it of local, regional, national or even international scale?
- Objective: What is the objective of the study? Are detailed results required or are approximate results sufficient to achieve this objective?
- Availability of resources: How much time and money is at hand to carry out the study? Is there a considerably high, average or low amount of resources?
- Pre-existing data: Is there already data at hand which is necessary for damage evaluation?
 Of which type is that data?

Step2: is to choose which kind of direct, tangible damages should be included in the analysis (see Section 2.3.3).

Step3: is to gather the necessary information for flood damage evaluation: inundation characteristics, land use data, information on the value of elements at risk and depth/damage functions (see Section 2.3.1)

Step4: For the calculation of damages the information gathered in step 3 has to be related to each other. By adding up the estimated damages to each land use unit the total damage of each flooding scenario can be calculated. Especially for meso- and micro-scale studies or when the objective of the study requires spatially differentiated results (identification of hot-spots, evacuation planning) we recommend not only calculating total damage amounts but also carrying out damage mapping by means of a GIS. Even the most detailed approaches of flood damage evaluation are still characterized by uncertainties in their results. To provide good decision support, these uncertainties should be documented, e.g., by minimum and maximum damage amounts or by confidence intervals.

3. Problems in current practice of flood risk management

Currently, the evaluation of alternative measures is mostly done by means of cost-benefit analysis (CBA). In this case, the costs of a certain measure are compared with their benefits in terms of risk reduction. In theory, this procedure leads to an efficient allocation of funds and finally to an optimized protection against flooding. For both parts, risk assessment and the evaluation of risk mitigation measures (CBA), it is required to quantify flood risk as exactly as possible. In this context, three deficits in today''s practice of flood risk management can be identified (Meyer, 2009):

- a. The current practice of flood risk assessment and cost-benefit analysis still focuses on economic damages, especially damages on buildings and their inventories. In contrast, social and environmental effects of flooding, like e.g. loss of life, stress or destruction of biotopes, are often not considered. This is partly because they are not, or at least not easily measurable in monetary terms and hence not comparable with economic damages. In consequence, flood risk management often manages only certain parts of flood risk. On that basis, an optimized allocation and design of flood mitigation measures cannot be ensured
- b. The spatial distribution of risks as well as of the benefits of flood mitigation measures is rarely considered. That is, the evaluation and selection of appropriate mitigation measures is mostly based on their overall net benefit. Therefore, it is often not considered which areas benefit most from a measure and which areas do not. This may lead to **spatial disparities of flood risk** which are not desirable or acceptable.
- c. Uncertainties in the results of risk assessment are often ignored. Although sophisticated methods in all parts of risk analysis and assessment have been elaborated over the past decades in order to give a reasonably exact estimation of flood risk, the results of risk assessment are still to some degree uncertain or imprecise. These uncertainties are often not communicated to the decision makers, i.e. a non-existent precision of estimation is pretended. This might facilitate the decision for the decision

maker but reduces the scope of decision and could lead to a solution which is not optimal. Figure 7 below shows a graphical representation of uncertainties in risk assessment.



Figure 7. Uncertainties in risk assessment

In this context, multicriteria analysis (MCA) is recently developed as an appropriate method of incorporating all relevant types of consequences without measuring them on one monetary scale by Meyer, 2009. It provides an alternative to the complex monetary evaluation and internalization of intangible consequences in a cost-benefit analysis as emphasized in Section 2.3.3.

4. Flood risk management examples

4.1 Investment Scenario Modeling (Excerpted from Environment Agency Wales, 2010)

This example uses **financial modeling** to consider the current levels of investment in building and maintaining river and coastal flood defenses, and the predicted impacts on flood risk of various changes in investment in the future.

4.1.1 Investment scenario modeling

Five different investment scenarios (see Box 1 below) have been used to examine a wide range of investment options. Scenarios 1 and 2 are financially constrained, whereas 3 to 5 are not limited by finances but by the requirements of the scenarios.

Over the next 25 years investment will be required to maintain the existing asset stock, construct new defenses and replace those defenses that reach the end of their design life. In addition, **climate change** impacts will progressively reduce the level of protection provided by current defenses and will increase the requirements for maintenance investment. This is particularly the case around the coast, where defenses will be subjected to more frequent and violent storms and wave action. The five investment scenarios take into consideration these factors, and therefore they represent progressively increasing levels of investment.

Box 1: Investment scenarios modelled

- 1. 2009/10 allocation with inflation increase going forward;
- 2. 2009/10 allocation with inflation plus £1m year-on-year increase as suggested in the *Future Foresight Flooding report*;
- 3. Allocating and costing the policies contained in Catchment Flood Management Plans and Shoreline Management Plans;
- 4. Target those properties at significant risk of flooding, where the benefits of doing so are at least equal to the costs;
- 5. As for scenario 4, but also maintaining the current level of risk for all other properties, regardless of the cost.
 - Scenario 1 maintains the current total level of annual investment (public and private) of approximately £44m into the future and over the 25 year assessment period.

- Scenario 2 also includes an additional £1m year-on-year increase. In this assessment it is
 assumed that all this additional investment is directed to river and coastal flood defenses,
 rather than other flood risk management activities.
- Scenario 3 considers the investment required to deliver the policies contained in the current published Catchment Flood Management Plans and Shoreline Management Plans. As above, this assessment assumes that these policies are delivered only by investment in flood defenses whereas the Catchment Flood Management Plans advocate a much wider range of actions to complement investment in defenses.
- Scenario 4 targets the investment to locations of highest flood risk and where the benefits are at least equal to the costs. This represents an economically justified investment.
- Scenario 5 is the same as scenario 4 except that further investment is required to maintain the current level of risk for all other properties regardless of cost. These locations may have costs which exceed the benefits. They are more difficult and therefore more costly to defend.

4.1.2 Modeling risk and uncertainty

Estimates of both risks and costs are based on assumptions and as with all modeling there are uncertainties that are reflected in the results. Future costs cannot be precisely known and are estimated to have a margin of error of plus or minus 25%. The margin of error for future numbers of properties at risk and the future damages is also at least plus or minus 25%. Hence, the results are not definitive or exact; they are indicative of the possible costs and flood risks.

4.1.3 Summary for flood risk of different investment scenarios: results from scenario modeling

Figure 8 shows the numbers of properties at significant and moderate flood likelihood in 2035, for each of the scenarios. According to the National Flood Risk Assessment (NaFRA) in UK classified the flood risks depending on the chance of flooding in any year at that location, i.e., Low(1 in 200 chance), Moderate (1 in 200 to 1 in 75), and Significant (1 in 75) (Environment Agency Wales, 2010). Figure 9 a) and b) show the "net benefits" (that is, benefit minus cost) and the "benefit" (that is flood damages avoided) of each investment scenario, respectively.



Figure 8. Investment scenarios: properties at significant and moderate likelihood of flooding in 2035.



Figure 9. Investment scenarios: a) the net benefit of investment; b) the benefit of investment

In summary the results of the scenario modeling show:

- All scenarios are economically positive and justifiable investments in terms of the flood risk benefits gained.
- For all scenarios there are significant net benefits of around £20 billion or greater and the benefit-cost ratios are all around three or greater, indicating a significant return on investment.
- The net benefits of scenarios 1 and 2 are comparable. However the number of properties in the significant likelihood category increases substantially under both scenarios from the present day 65,000 to almost 100,000 in 2035.
- The additional investment of scenario 2 does generate approximately £1 billion more benefit than scenario 1 over 100 years. However scenario 2 also costs approximately £1

billion more than scenario 1 over the same period. Therefore the net benefits are comparable.

- Substantially increased and high levels of investment are needed to maintain the 2035 risk level, (considering significant and moderate likelihood) to around the current level.
 Scenario 3 is broadly comparable to the present day, and requires an annual spend of around £135m in 2035. This is around three times the current spend.
- Even higher levels of investment are needed to reduce the numbers of properties in the significant and moderate likelihood categories. Scenario 4 indicates an annual spend of around £170m by 2035 would achieve this. This is around four times the current level of investment.
- Scenario 5 has an estimated annual spend of £290m per year in 2035 around seven times the current levels. However the number of properties in the significant and moderate likelihood categories are not substantially less than those for scenario 4. This is because scenario 5 also maintains current level of risk for all properties whereas scenario 4 does not. This means that under scenario 5 defenses are replaced to keep pace with climate change, and many of the benefits from scenario 5 are not realized until after year 25.

4.2 GIS-based multicriteria evaluation of flood damage and risk (Excerpted from Meyer, 2009)

Geographical information systems (GIS) with their ability to handle spatial data are an appropriate tool for processing spatial data on flood risk. In our framework we therefore describe and test approaches which combine MCA with GIS. In addition, some possibilities of integrating the uncertainties in the results of risk analysis in this GIS-based MCA approach are presented in order to provide good decision support for the responsible decision makers.

Therefore, we firstly discuss and develop a methodological framework for spatial MCA for flood risk mapping and secondly apply and test our approach at the FLOODsite pilot site Mulde, a tributary to the Elbe River.

4.2.1 A methodological framework

The process of MCA can be divided into different steps (based on Munda 1995):

- 1. Problem Definition
- 2. Evaluation Criteria
- 3. Alternatives
- 4. Criteria Evaluation
- 5. Criterion Weights
- 6. Decision Rules
- 7. Results & Sensitivity

In the following we will briefly explain the different steps and hereby describe the approach we applied at the Mulde pilot site. From Section 4.2.2 to 4.2.8, we will describe the details about this framework.

4.2.2 Problem Definition

At the beginning of any decision making process the problem needs to be recognized and defined. With regard to flood risk management the underlying problem can be structured into two parts:

Multicriteria risk assessment

First of all, the current magnitude and spatial distribution of flood risk needs to be identified in order to find out where further mitigation measures are necessary. This *multicriteria assessment* of different areas is therefore an important prerequisite for *multicriteria project appraisal* below.

Multicriteria project appraisal

After identifying high risk areas, the second part of the decision problem is to find the best strategies or measures to reduce flood risk to an appropriate level. These mitigation measures need to be evaluated in order to find the best alternative or combination of alternatives.

In this report we concentrate mainly on the *multicriteria risk assessment and mapping*. Nevertheless, our approach can be also used as a basis for the evaluation of risk management measures. However, the problem is that a relatively high number of alternatives might restrict the MCA-approaches practicable.

4.2.3 Evaluation Criteria

The choice of an appropriate criteria is an iterative process where experts in the field of interest are firstly asked independently from each other to identify relevant criteria. These results are then discussed together and the experts can revise their choice in a second round. This process is continued until a consensus is achieved about a common set of criteria. For our multicriteria assessment of flood risks at the Mulde River we apply the following risk criteria:

- Economic: Annual Average Damage
- Social: Annual average affected population and Probability of social hot spots (hospitals, schools etc.) being affected.
- Environmental: Erosion potential (of material), Accumulation potential (of material), and Inundation of oligotrophic biotopes

4.2.4 Alternatives (Spatial Units)

This is the section to compare alternatives with those derived in Section 4.2.2

Multicriteria risk assessment and mapping

<u>Multicriteria risk assessment does not really compare different actions or decision alternatives</u>. It is an assessment of different areas regarding their risk status. Hence the alternatives to be compared in this case are different **spatial units** within the research area. Depending on the underlying spatial data, or the GIS-model chosen, these spatial units to be compared could be grid cells (raster GIS) or points, lines and polygons in a vector GIS.

Multicriteria project appraisal

The second multicriteria problem deals with the comparison and selection of alternative flood mitigation measures. I.e. the decision problem is to choose among a given set of flood risk management measures ranging from structural measures like dikes and dams to non-structural measures such as land use changes or warning systems.

4.2.5 Criteria Evaluation: Risk Maps

For each alternative or grid cell the performance of each criterion needs to be evaluated. Regarding GIS-based flood risk assessment, **the result is a risk map for each criterion**.

For the practical application of flood risk assessment this means that the negative consequences have to be evaluated <u>for flood events of different probability</u>. Based on these damage evaluations for different events a damage-probability curve can be constructed (see Figure 3 in Section 2.1). The risk (or the annual average damage) is shown by the area or the integral under the curve.

The basis for all our damage evaluations in the Mulde pilot site is inundation data for events of different exceedance probabilities calculated by a 1D-hydrodynamic modeling by HELMHOLTZ Center for Environmental Research(UFZ) (Schanze et al., 2008). For each of these events the inundation area and depth is mapped for a grid with a spatial resolution of a 10m (See Figure 10 below). Damage is calculated for each of these grid cells, so that a damage map for each of the events mentioned above is produced. By using the risk formula described in Section 1.2 above, the annual average damage per grid cell can be computed. All computations are carried out by the **software tool FloodCalc** (Scheuer & Meyer 2007). It allows the uploading of grid data of inundation depth, value of assets, inhabitants, environmental values and to combine them with different sets of depth/damage function and thereby producing damage and finally risk grids.

It is important to note that all methods chosen here to estimate the different risk criteria (inundation modeling as well as damage evaluation) are fairly approximate approaches. This means risk estimations of single raster cells may have high uncertainties.



Figure 10. Expected inundation depth for a 200-year flood event (City of Grimma)

For the economic risk criterion, flood damage for each of the events mentioned above is calculated by means of a meso-scale damage evaluation approach (Meyer 2005). The general procedure is the following:

- The total value of assets at risk and its spatial distribution are estimated based on data from official statistics (the net value of fixed assets for different economic sectors) which is then assigned to corresponding land use categories.
- Relative depth/damage curves are then used to calculate the damaged share of the values, depending on inundation depth.

Methodological uncertainties in damage evaluation are shown by applying <u>1) different spatial</u> <u>modeling keys of asset value to land use categories and 2) different sets of depth/damage</u> <u>curves</u>. An annual average damage per raster cell is calculated based on the different damage estimations for inundation events of different exceedance probabilities (1:10, 1:25, 1:50, 1:100, 1:200, 1:500). This is conducted for the mean as well as for the minimum and maximum damage estimations so that the final output is a mean, minimum and maximum annual average damage per grid cell, accordingly. The mean annual average damage is shown in Figure 11.



Figure 11. Annual Average Damages (AAD) (City of Grimma): mean estimation

For the environmental risk criterion, a simple yes/no damage function as shown in Table 3 is applied for each three criterion, depending on if the area is affected or not, and then calculate the sum of the values given for each criterion to estimate a first environmental impact potential of a flood. Analogous to the calculation of economic damage, damage maps for environmental consequences can be produced for each flooding event. Each raster cell can hereby achieve "damage values" between 0-3. Based on these different damage maps an environmental risk map
is calculated by using the risk formula described in Section 1.2. This risk value can be interpreted as annual average environmental consequence. In Figure 12, these values are already standardized in values from 0 to 1.

Indicator / Criterion	Potential damage (risk)		Explanation / notes
	yes	no	
Erosion	1	0	where erosion of fine grain material occurs pollutants might be mobilised and transported (pollutants = heavy metals bond at clay minerals and organic matter; nutrients such as Phosphorus)
Accumulation	1	0	same as erosion but creation of new polluted sites due to accumulation of the transported material
vulnerable oligotrophic biotopes	1	0	a longer inundation (>1 hour) of oligotrophic biotopes (see list below) might negatively affect these biotopes in form of eutrophification or drop of the number of species
final assessment	Σ	Σ	





Figure 12. Environmental risk (City of Grimma): standardized values (0-1)

For the social criteria (affected population & social hot spots), the spatial distribution of the affected population is calculated by a meso-scale approach more or less in the same way as the asset values (Meyer, 2005): Therefore, the number of inhabitants is taken from official statistics on municipality level and broken down to corresponding land use categories. By intersecting this population density map with the inundation data the number of affected people can be estimated

for each event. According to the risk formula, the number of the annual average affected population can be calculated (Figure 13). As "**social hot spots**" the locations of hospitals, schools, old people's and children's homes are identified. By intersecting the map with the social hot spots with the inundation maps it can be determined for which inundation scenario the hot spots would be affected. By applying the risk formula an approximate estimation of the probability of being affected can be calculated for each hot spot (Figure 14).



Figure 13. Annual affected population (City of Grimma)



Figure 14. Social hot spots at risk and their probability of being flooded (City of Grimma)

4.2.6 Criteria Weights

Regarding a multicriteria flood risk assessment, the decision makers have to decide on the **relative importance** of the different economic, social and environmental risk criteria. Our software tool provides the possibility to carry out the point allocation approach, a rating technique where 100 points have to be allocated among the criteria. The criterion ranked first is given 100 points and the following criteria receive points according to their relative importance to the preceding criterion.

4.2.7 Decision Rules

The decision rule aggregates the different criteria maps under consideration of the weights given to each criterion. It can be therefore considered as the core of MCA. Two different approaches are used: the Disjunctive approach and an MAUT approach (simple additive weighting) to be implemented in our software tool.

Disjunctive approach

The general idea of the Disjunctive approach is that the decision maker has to define a threshold level for each criterion. E.g. in order to select areas which have a high risk of flooding, the decision maker has to determine for each risk criterion a critical value which defines the border between low/acceptable risk and high/unacceptable risk. If this threshold value is exceeded in only one of the criteria the area is selected as a high risk area. This simple approach seems to be appropriate e.g. for a quick screening and pre-selection of high risk areas.

Multi attribute utility theory approaches (MAUT)

The general concept of additive MAUT approaches is to generate a weighted average of the single criterion values for each area (or alternative). The procedure for this is the following:

- Standardize the criteria scores to values (or utilities) between 0 and 1.
- Calculate the weighted values for each criterion by multiplying the standardized value with its weight.
- Calculate the overall value (utility) for each alternative by summing the weighted values (utilities) of each criterion.
- Rank the alternatives according to their aggregate value (utility).

Figure 15 shows a MAUT approach applied.



Figure 15. Standardised multicriteria risk (City of Grimma) : equal weighting of economic, social and environmental criteria

4.2.8 Results and Sensitivity

Uncertainty and sensitivity analysis can be done to investigate how the changes or errors in the inputs of the analysis might affect the results. These changes or errors can concern either the criterion values, i.e. uncertainties in risk assessment, or the weights given to the criteria. As an uncertainty analysis, the economic criteria score uncertainty was considered by calculating a mean, minimum and maximum annual average damage, depending on the spatial modeling of asset values and the set of damage functions chosen. Furthermore, the sensitivity of the overall results to the weights given to the criteria also was investigated. For the simplification, the Figures associated with those analysis are not presented herein.

5. Recommendation and Future works needed

Summarizing the theses above, some recommendations can be given for the improvement of flood risk assessment in order to provide better support for flood risk management decisions:

In overall perspectives,

- Flood risk assessment is always to some degree uncertain, but these uncertainties in the results should be documented in order to provide decision makers with information on the quality of the data they are using as a decision support.
- Social and environmental flood risks should be also considered in an overall risk assessment e.g. by means of multicriteria analysis (MCA).
- The spatial distribution of flood risks and risk reducing effects of mitigation measures should be shown by appropriate risk mapping approaches.

For the practical point of views for the IOWA Flood Center (IFC),

- Based on the information above, we need to initiate the project for flood risk assessment and reduction management for the state of Iowa by deploying available methodologies such as MCA or approaches listed in Table 1 in Section 2.3.2 and by testing available software.
- Identified software for Flood Risk Management
 - Floodcalc (Scheuer & Meyer 2007) which is used for MCA in this paper.
 - HR-Wallingford software (Flood risk 2008, Issue13)
 - ✓ **RASP (System based risk model)** to support different flood risk management decision levels (Also see Table 1 for the 3^{rd} Macro Scale Approach).
 - ✓ RASP-NaFRA: allows a rapid assessment of the national risk picture, enabling decision makers to quickly indentify high risk areas as well as where resources should be focused.
 - RASP-strategic planning with the modeling and decision support framework
 2 (MDSF2): Embed the RASP methods within the MDSF. Once complete, this will incorporate risk based methods and defense performance in the original MDSF(modeling and decision support framework)
 - ✓ RASP-Performance based asset management (PAMs)

✓ **RASP-Long-term planning**

The details about the software should be investigated.

 For the inundation modeling, Infoworks CS (2D urban flood modeling by HR-Wallingford), Delft3D (coastal waters and estuaries and rivers) and SOBEK (urban water management) by Deltares can be alternatives compared to expensive MIKE by DHI Software.

- Useful links for the flood risk management information
 - Environmental Agency Flood update: <u>www.environment-agency.gov.uk/flood</u>
 - FRMRC (Flood Risk Management Research Consortium) -<u>www.floodrisk.org.uk</u>
 - Risk and uncertainty: FRMRC reviewed the different techniques available for uncertainty estimation for different types of flood risk management applications (see www.floodrisknet.org.uk/methods)
 - Flood related papers and information <u>www.Floodsite.net</u>, <u>www.floodrisk2008.net</u>
 - ↓ Investigation of extreme flood processes and uncertainty www.impact-project.net
 - Flood risk assessment and mapping –
 <u>http://www.hrwallingford.co.uk/index.aspx?activities=floods&topic=Flood risk</u>
 <u>assessment %26 mapping&facets=floods</u>
 - HR Wallingford publication <u>http://eprints.hrwallingford.co.uk/</u>
- The future works needed for the establishment of solid framework for the flood risk management plan would be as Figure 16 below (FRMRC2- Paul Sayers, 2010).



Figure 16. Ideal framework for flood risk management

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International Perspectives in Water Resource Science and Management: Living with Floods The Netherlands & United Kingdom The University of Iowa, Summer 2010

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