

# Uncertainty, Systems and Information Behavior in Climate Change Adaptation: Protecting Cultural Resources in our National Parks (Report)

October 30, 2013

R. Jay Flaming

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## **Executive Summary**

The “Information Systems for Cultural Heritage Climate Change Adaptation, Disaster Response, and Heritage Stewardship” collaborative research project was initiated in 2010. In spring of that year, R. Jay Flaming, a PhD student in archaeology from the University of Washington and a Pathways program NPS employee, went to Washington DC on a temporary duty assignment to help the directorate plan for climate change response for cultural resources. This work was interrupted by the MS Canyon 252 oil spill before it was completed. This Cooperative Ecosystem Study Unit grant was intended to help complete some of this research. The goal of the project was to provide academic research to support adaptation decisions. It was hoped that this would also lead to a PhD dissertation on the subject. This project ran into many setbacks, including staffing changes within NPS, lapses in government funding, changes in NPS strategies that negated entire lines of inquiry mid-study, and the University of Washington faculty’s decision that the project as agreed upon was not appropriate for a PhD thesis. Nevertheless, numerous meetings, presentations, and conversations were sparked by the project.

## **Papers, and Presentations**

### **George Wright Society Meetings, 2011**

March 14-18 2011, New Orleans

Jay Flaming co-organized and presented a joint meeting on vulnerability assessment with John Gross.

### **George Wright Society Meetings, 2011**

March 14-18 2011, New Orleans

Jay Flaming presented a poster session on issues of integrating geospatial data.

### **FEMA Region X Workshop: Implementing Preparedness in Your Organization**

April 18 2012, Bellevue, Washington,

Workshop Facilitator/Presenter: Implementing a Program, Promoting, Evaluating & Sustaining a Program. Jay Flaming presented, and facilitated discussions on risk assessment and response, especially focused on the capacity of youth to support these missions within

organizations. (Funded by outside partners)

### **George Wright Society Meetings 2013**

March 2013, Denver Colorado

Planned and prepared to present in a roundtable discussion of climate change (arranged by Marcy Rockman in WASO) but the meeting was cancelled due to government funding lapse.

### **Alaska Anthropology Association Meetings: “Northern People and Landscapes in Times of Change”**

February 29 - March 3, 2012, Seattle WA

Chaired a session on Archaeological Compliance and Survey, especially focused on monitoring of sites due to climate change impacts, and presented a paper entitled

“Analytical Monitoring for Cultural Resource Vulnerability and Risk Reduction”.

### **International Congress on Science and Technology for the Conservation of Cultural Heritage**

October 2-5 2012, Santiago de Compostela Spain,

Invited Lecturer, presented a keynote entitled: “Challenges of GIS for Heritage Management”.

(Travel funded by outside partners)

### **Papers and Projects:**

Paper 1: Information Needs Assessment

Paper 2: The Need for Action

Paper 3: The Cydoemus Project, a framework for integrating GIS data uncertainty

### **Meetings**

Preliminary Scoping meeting: June 14, 2011 in WASO, Washington DC re:vulnerability, linking GIS and databases for analysis

Organizational Meeting 1: January 21, 2011, U.S. National Park Service Offices, Seattle, WA

Organizational meeting 2: September 24 2012, University of Washington, Seattle WA

Organizational meeting 3: August 2013, WASO

## **Academic Research:**

Topics explored at the University of Washington:

- Vulnerability assessment models. (Through FEMA, UW's school of Architecture, and Bob Freitag, a floodplains and coastal inundation expert)
- Tactics for integrating data: metadata, schemas, GIS (through UW's iSchool)
- Analysis of risk through computer modeling (independent research)

## **Other Outcomes:**

Using the knowledge gained from this research, Jay Flaming sat on numerous committees on climate change adaptation, Resource Stewardship Strategies, and cultural resources performance measures to provide insight on methodologies and techniques. He also provided countless support calls, emails, and served as a general clearinghouse for information about GIS modeling for climate change within the cultural resources community.

# Paper 1: Information Needs Assessment

## Introduction (the need)

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“Perfection of means and confusion of goals seem in my opinion to characterize our age.”  
-Albert Einstein

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Cultural resources, such as archaeological sites or historic buildings, are vulnerable to destruction by human and natural causes. How can we protect these in the future, given the uncertainty of an era of changing climate? Climate change mitigation experts are at work trying to change human behaviors linked to increasing temperatures, but it is critical at the same time to work on adaptation, how we will deal with the reality of the future. While working for the National Park Service’s (NPS) response to the Mississippi Canyon 252 oil spill and the destruction of the Deepwater Horizon offshore drilling rig, I found out first-hand how difficult it can be to apply our existing practices and information resources to making decisions about cultural resource protection on such a grand scale.

The National Historic Preservation Act (1966) dictates that federal agencies must take care during their undertakings (such as construction projects, or oil spill cleanup) to protect cultural heritage, and undergo consultation with people or groups related to resources within the area of effect. Beyond this, however, the NPS charter has a higher calling to

“...conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.”

(NPS Organic Act 1916)

This is a call, not only to respond to the regulatory processes of the National Historic Preservation Act, but to actively conserve our cultural heritage against any damaging force, whether natural or anthropogenic. Indeed, in the case of climate change, these boundaries are blurred beyond meaning. Climate change hazards are natural forces responding to humanity’s behaviors.

The goal of climate change adaptation for cultural resources is to take action to minimize the loss of value to the public, both today and in the future. This loss may be brought on by a number of forces attributable to changing climate, including such physical threats as erosion or fire, or more ethereal losses due to shifting populations or loss of cultural context.

In the past, there has been no formalized risk response system within the United States National Park Service (NPS) to ‘natural’ threats (those that are not directly the result of an intentional endeavor), such as from disasters, erosion, or succession of vegetative environments. Few, if any, of these threats are new or are solely the result of climate change. Instead, climate change results in an intensification of these forces, and an extension of these threats into new areas.

This report takes the stance that climate change hazards are not unique, and that they have similarities with and overlap with other natural or human-initiated changes (such as those from projects). While response to human projects has a long-established protocol, responding to natural or indirectly human-caused effects is less clear. We need a unified approach to assessing risk from all sources, including climate change, and decide how to mitigate this vulnerability. Carrying this out requires knowing what resources may be affected, who cares about them and should be consulted, and what the potential effects may be. Officials and consultees must make difficult decisions. How can we improve information flow and access about these resources, and how can our practices spur protective action?

Decisions about what preservation actions are needed, whether they are feasible, and which actions to prioritize, while not easy or even necessarily having a single right answer, are approachable given sufficient access to information. They cannot be made by an automated system or by computer, but must be made by people, and must be made in consultation with multiple stakeholders. However, in the current situation within the National Park system, insufficient infrastructure exists to support such decision making, and consultation parties cannot sufficiently assess the situation in order to provide input. Our databases and research tools must present the information required to make these choices, and be firmly grounded in an accurate understanding of the information needs and behaviors of the people involved. Responding to this increased threat requires proactive preservative intervention. Dispatching such intervention in the most efficient and effective way possible is a serious preservation challenge for public land stewards around the world.

Within this paper, I argue from a number of general assumptions:

1. The core of adaptation is individual protective action. All actions and programs, whether strategic, operational, national, regional or park based are reducible to the need to protect individual resources, and should be guided by that need.
2. It is most efficient to use what structures and tools we've got to the fullest extent possible. However...
3. We should not use an existing structures if they do not work.
4. We must consider contextualized networks and landscapes more than individual properties or artifacts when choosing actions. The cultural value of resources in aggregate may greatly exceed the sum of their individual values.
5. Decisions must be made competently: this means they are made by qualified individuals with full access to all available information. People should be given the opportunity to see all relevant information and be able to follow the life history of the information sources they are given, and assess their reliability.

## Definitions

Discussing climate change hazards, threats, and vulnerability is challenging, due to a lack of consensus about these terms, or where these concepts originate. In preparing this paper, I have examined traditions from the military, civilian and academic spheres, specifically the Department of Energy, the Department of Defense, the United Nations University, and corporate risk assessment. In 2006 the United Nations University Institute for Environment and Human Security chartered an expert working group called "Measuring Vulnerability." (Birkmann 2006) Their first publication was a glossary to attempt to create some uniformity in terminology, which one author called "Babylonian Confusion." Even so, in their own papers following this publication (and even within it) there is little clarity.

Given the United Nations group's inability to establish any succinct vocabulary, for the purposes of this project I will use the following terminology:

- Hazard: a force that can damage cultural resources, such as erosion or fire. These generally fall into two classes: those that damage the resource



itself (such as fire on a wooden structure) and those that compromise the surrounding support structure (erosion). Threat is a synonym for hazard, although it has a more specific meaning in some NPS databases, so we avoid using it here whenever possible.

- **Vulnerability:** the main components of vulnerability are exposure, sensitivity, and significance. That is, how likely is something to be exposed to a hazard, and how likely, given exposure, is damage? If this resource is lost, what will its impact be? In some contexts adaptive capacity is defined as a third component (how able something is to respond to its own threat exposures and sensitivity).
- **Exposure:** Likelihood that a resource will be within the influence of a given hazard. This is always relevant to a period of time. The probability of exposure to inundation for a site on the coast might be 20% today, and may be 90% in 30 years. Hazards already occurring and affecting resources are given probability of 100%.
- **Sensitivity:** also known as susceptibility. Hazards may or may not damage a resource based on characteristics of that particular resource. A lithic scatter (workshop area of stone tools) in a dune area is more susceptible to wind damage than the Washington Monument, even though both are exposed to it. Sensitivity is the probability the resource will be damaged, assuming it is exposed. Damaged here means that the integrity of the site is reduced in such a way as to reduce its significance. Although some authors consider it separately, resilience is also a component of sensitivity. That is, if something is initially damaged by a hazard, but is able to recover, it was never sensitive to that hazard in the first place.

## **Vulnerability Analysis:**

The National Academy of Public Administration, in a 2008 report (Hodsoll et al 2008) recommended that the National Park Service incorporate vulnerability assessment into its management approach. Vulnerability analysis (sometimes called vulnerability assessment) is the process of finding the "chinks in the armor" of our national cultural heritage. It is primarily a formalized system for prioritization and assessment of preservation action. It asks the question "which resources are the most likely to be destroyed, what can be done about it, and which are the most important to protect first?" Our most critical tasks are to take action

at that apex.

Most people are familiar with some sort of risk assessment. There are two components that we can conceive of comprising risk: exposure and susceptibility. Risk assessment falls short, however, of considering the value of the asset to society, or systems at large. Vulnerability assessment adds a component of triage or prioritization, by identifying the key places a system may be at risk. Combining risk with importance in this way yields a measure sufficient to establish priorities and strategically plan our actions. So our information system must provide researchers with information about exposure, susceptibility, and relative importance. This information is needed by various stakeholders, including NPS cultural resource managers, NPS planners and high level managers, park visitors, and Native American tribal organizations or other consulting parties. These are needed in several contexts, including long term planning, daily work planning, and formal consultation. More specific information needs vary based on the model chosen for vulnerability analysis.

There are several formal models for working with these measures. These do not overlap perfectly in purpose or application, but here I consider them as alternatives, even though some amalgam may be constructed out of them (and indeed, some are hybrids of other approaches as well).

### **Formal Model 1: Disaster Response Model**

Citation: Freitag et al, 2009. Floodplain Management: A New Approach for a New Era (find others)

Freitag's model consists of 3 major components:

- Change modeling
- Predicting effects
- Utilizing capabilities to mitigate these effects.

This risk assessment model has a focus on being prepared so as to reduce negative impacts and maximize ability to capitalize on possible benefits. For example: in archaeology, benefits might include sites that are newly exposed (yet without being prepared and having sufficient staff, we might miss the exposure and lose the site to erosion or looting!). Ice patches, for example, are melting and exposing amazing artifacts almost every summer in Alaska and the north, but if those are not discovered almost immediately, they organic material decay once

exposed, and they are lost forever.

### **Change profiling**

Changes may be primary or secondary. For example, a primary hazard might be a flood. Secondary hazards might be erosion or landslides. This can lead to a complicated web, with climate change in this instance being the ultimate primary hazard, yielding dozens or hundreds of secondary hazards. For the purpose of analysis, it is usually more productive to think of each hazard more specifically, since each different secondary hazard from climate change has very different outcomes (desertification and sea level rise, for example, share very few aspects). Synonyms for change in this context include hazards, threats, disturbances, and vectors. When profiling change the main factors include timing, location, severity, frequency.

- Timing: when does this hazard come into play? Season, day of the week, night vs day, hours, etc?
- Location: where does it have an effect?
- Severity: how much energy is expended, or destructive power is unleashed, compared to background exposures?
- Frequency: how often does this happen within a given period of time? This can be tricky... some hazards may be frequent and regular, others sporadic and random, others seemingly random but actually slowly increasing in likelihood over time (like earthquakes).

### **Effect Modeling**

Key words and synonyms: consequence, exposure, vulnerability

Given exposure to the change profiled in step 1, what will happen to our resources? This means assessing the effect on built environments, natural environments, and systems. Effects are not inherently negative. They can be beneficial!

### **Mitigation planning:**

capabilities: what tools and resources we have available to make changes to vulnerability.

These are actions that can be taken to change the outcomes predicted in step 2. In common disaster related analysis, these are often quite indirect: training, building codes, etc. In our case, we can directly bring about many of our changes, because we are in a better situation (more command and control... we don't have to cajole private citizens to take actions they do

not want to undertake).

key words: Strategies, Tactics, Talents, Customs, Resources...

Adaptation can take the form of: Buffers, Retreat, Accommodate, Protect

Buffers:

## **Formal Model 2: Ecosystem Services Model**

(find citation:)

What is the basic unit we are considering to be vulnerable? A cultural resource or some service that they provide us?

What is a cultural resource? This is a dynamic definition, and pursuing a concrete definition is perhaps unfruitful, as the meaning is dependent on cultural values, not to mention governed by a body of law. However, we must remember that we do not want to disadvantage the values of future generations by assuming that today's values are the pinnacle or permanent. Thus, we must protect even more than is currently valued (which is, of course, the core value of preservationist thinking).

Resources vs Services

It is a po

What might a cultural analogue be to the ecosystem services model?

Services of cultural heritage resources:

- a library of the knowledge of the past about how to live
- elements of cultural identity
- stabilizing elements of governments and social institutions
- a physical component of history

Problematic terms: resilience. We are a preservation organization: by definition, our resources cannot recover, nor do they have adaptive capacity. We, however, do.

What is the basic unit of conservation, when we consider cultural resources or national heritage?

Ecosystems Services:

Envisioned by the UN

In many ways, ecosystems services seems like a jump forward. The basic unit is the actual value provided to us as people.

Problems:

- Ecosystem services are not the legislated unit of preservation
- It is difficult to nail down the services provided by CR
- Services are not what was in mind when the laws were passed, maybe not even in spirit of the law.
- Not possible to predict what services of the future might be. Conservation means we are playing a percentage game, trying to guess what that might be, and by doing so, we guarantee we will be wrong sometimes.

Cultural identity is more robust than people might imagine. The destruction of physical resources may have more value than their preservation ever would... for example, the demolition of Soviet era statuary or Hitler's bunker. For example, the current debate over preserving the relics of the dawn of the atomic bomb is about whether preserving these or destroying them best serves the public good.

Another issue is that services are renewable, but resources are not.

The basic unit of preservation matters for another reason. Many vulnerability assessment approaches also include a component of resilience or adaptive capacity. From an academic standpoint it is interesting to muse about the ability of a cultural resource to respond, but in the case of managing cultural resources it is not particularly useful. If our unit of preservation is a physical resource, their lack of adaptive ability is what makes them interesting... their features remain adapted to some prior condition, culture, or situation. Cultural resource literature calls this “retaining integrity.” From a practical standpoint, adaptive capacity can be considered a component of sensitivity.

In many ways, a services based approach is a powerful way to approach this problem. Yet the problems with formalizing this into practice outweigh the benefits to current legislation and policy oriented preservation approaches.

### **Formal Model 3: Scenario Planning**

Scenario planning is an approach aimed at dealing with highly uncertain futures. It is ideally applicable to unpredictable events. Social events.

Scenario planning was intended, not to address specific outcomes so much as generate an adaptable mindset and flexible thinking, by allowing people to think about responding to a variety of outside-the-box possibilities.

For example, scenario planning

When hazards are predictable, can be monitored, or are measurable, scenario planning gives up much power, adds confusion, loses broad applicability.

It retains much power for what-if thinking, to promote creativity.

### **Overall Discussion:**

GIS Models of Vulnerability Assessment:

With the exception of

In the context of this paper, preserving cultural resources means preserving:

- data (numerical, textual, digital representations of a resource)
- the physical properties of objects and places
- cultural knowledge and associations with the physical objects and places. (In the context of this paper, I do not consider more ethereal resources, but rather physical vestiges which are directly manipulable and protectable).
- the opportunity to assess prior research/reinterpret old stories

### **Information Needs (Common to all models)**

The process:

In general:

Gather models of anticipated change. The changes that affect cultural resources include

changes in humidity, erosion, insect and pest regimes, soil temperatures,

## **Information Resources Available**

Databases, such as the Archaeological Sites Management Information System (ASMIS), are the foundation of our external information resources. They are also the most logical portal for people to access the decision support resources proposed here. Subject specific databases exist for archaeological resources and historic resources, and the Cultural Landscapes Inventory cross-cuts both. Databases can provide information about the exposure component of vulnerability, but are more useful for the **susceptibility** (what kind of site is it? what materials does it contain?) and **importance** (is this important at a local, county, state, national, or international scale?) Geographic Information Systems (GIS) are also a critical component of this system. Many primary hazards are spatially patterned and can be modeled in a GIS, such as erosion, fire, and coastal flooding. GIS information is primarily about the **exposure** component.

Intermediate paper???

## **Capacity**

"Do a lot of prototyping and reconfiguring as it hits the real world"

This document supports a need for technical cultural resource staffing at a regional/network level. The need to manage information has increased dramatically, with new tasks and technical skills required to do them. Changing how we structure these tasks will improve our data quality, research ability, and efficiency. This document is written primarily concerning archaeology, but could apply to other aspects of CR.

What is the need?

Cultural resource managers are being asked to respond to climate change, improve data quality, increase site visits, and bring old data into new standards.

Nearly every PMIS project proposal for climate change response in cultural resources includes a significant GIS component.

Nationwide parks are going to be converted to a new centralized cultural resources GIS data format.

What is the current model?

Service wide, there appear to be three general paradigms of cultural resources task management and staffing: Center Focused, Region Focused, and Park Focused.

Center focused means an area with a strong regional archaeological resources center, such as the Southeast Archeological Center or the Midwest Archeological Center. Most tasks are performed by the center staff.

Region focused means an area where a large central staff, but reduced staff in parks. Most tasks are performed by regional archaeologists.

Park focused means an area where central staff are reduced, and more staff are located in parks.

#### Information Tasks

Center focused

(MWAC, SEAC):

Region focused:

Park focused:

develop information tools

Center, WASO

WASO

WASO

data entry

Center staff

STEP/seasonal staff

STEP/seasonal staff

record/data maintenance

Center staff

Regional staff

Park (Network?)

research/analysis tasks

Center staff

Regional staff

?



support

Center staff

Regional staff

Regional staff, network staff

clearances, etc

Center staff

Park staff?

Park staff/Network staff

fieldwork

Center staff

Regional staff, park staff, contractors

Contractors, park staff, seasonals

This can vary by sub-program. In archaeology, the PWR is park focused. In most units of the NPS, cultural landscapes are region focused.

What is wrong with the current model for PWR?

Our systems are not used on regular basis for actual research, but instead for performance benchmarking. Region and center focused regions are more prepared to handle changing technology and efficiently use their information structures to actually enhance park operations. The park focused model has many benefits, especially reducing the perception of management overhead and strengthening connections with the on-the-ground situation in the parks. CR staff are more easily available to consult with park staff. It is also more amenable to a project-funding paradigm with low base funding. However, there are some negative consequences, at least from an information management perspective.

Consistency: most data entry and many fieldwork projects are conducted by either student employees, seasonal staff, or contractors. The result is that data entry, terminology, and field recording processes vary dramatically from year to year and project to project. It is impossible to create vulnerability analyses or track damages without consistent baselines of data.

Specialists: park centered CR staff must be able to wear many hats. Information technology skills, such as GIS and database manipulation, can only be a small part of their education and ongoing training. The world of GIS is changing too dramatically to remain current in this

situation. Some analysts believe that in the last decade, classes taken by students in GIS and information technology are often obsolete before those students graduate (Twiggs & Oblinger). It is difficult to maintain this kind of continuing currency where GIS and database tasks are an additional duty and not a focus.

Innovation: We compensate for a lack of staffing and dedicate personnel by waiting for technological solutions from WASO. WASO staff are often not connected to the situation on the ground. Databases and data models are built by specialists in DC, and data entry is done by temporary staff in parks with no effective path for feedback into the design of these structures.

Institutional longevity: Seasonals, students, and contractors are all by definition short term workers. Knowledge gained and feedback generated by these people is often lost. This is particularly critical in a rapidly changing environment. Also, parks may go for years without cultural resources staff. In this case, old data and systems are often nearly a complete loss, since the new staffer must try to parse out the pre-existing information systems, file structures, etc.

Do we need a different kind of organization, different staff, or more staff for these tasks?

Yes.

Cultural resource information staff specialists are needed as an intermediate level that provides longevity, consistency, technical prowess, and yet are closely connected to park operations. This is particularly true due to the trajectory of GIS, database, and IT technology, both within the service and in the world at large.

Integration of GIS and databases is nearly complete. Most major database systems now provide GIS functionality directly inside them, and most modern GIS products are basically front ends to databases. However, the NPS still uses these as separate systems.

A recent summit between the Obama administration and industry leaders has tasked the executive with moving away from specialized IT solutions with long development cycles (and obsolescence and cumbersome outputs as a result) to using off the shelf expedient tools. This means that we will need less focus on design teams in WASO, and more localized expertise in the middle to adapt these tools to localized conditions. New products will be expected to be in near-perpetual Beta status.

But isn't that the role of GIS staff? Shouldn't these specialists be dedicated to GIS itself, not cultural resource GIS/Database specialists?

In the last decade there has been a change in how GIS services tend to operate within organizations.

Old model: GIS professionals produced cartographic products that were consumed on paper or as graphics.

New model: GIS professionals design structures and systems. Users access these structures using GIS desktop products or web GIS tools.

The role of the centralized GIS cartographer is changing to a systems administrator and consultant. Researchers and managers are expected to have discipline-specific uses and knowledge of GIS. A quick check of USAJobs shows 202 jobs requiring GIS skills, but only 4 are actually dedicated GIS positions. We cannot expect to send GIS tasks off to an office, to be returned to us as a graphic or map anymore.

Don't data models and centralized databases (like ASMIS 4) fix consistency problems?

No.

The implementation of a GIS data model is still up to the individual park. The current CR-GIS data standard, for example, could be implemented in dozens of different ways, using different technologies. The data standards provide for consistent frameworks, not consistent data. They do not reduce the need for technical skill on the part of consumers. Centralized web databases reduce technical requirements on users, but make analyses more complicated and intimidating.

Data entry into ASMIS still requires interpretation. Linking ASMIS queries with GIS analyses requires expertise.

## References

The Virtual University By Carol A. Twigg and Diana G. Oblinger. A Report from a Joint Educom/IBM Roundtable, Washington, D.C.

November 5-6, 1996

Castelli

<http://www.federaltimes.com/article/20100124/IT03/1240303/-1/RSS>

# **Paper 2: The Need for Action: Overcoming Uncertainty**

“The ancestor of every action is thought” -Emerson

Practicing Archaeology for Conservation

The most critical need is to reduce barriers to action. The fundamental barrier is uncertainty. We can change our practices and structures to reduce that uncertainty or work around it.

Question: What are we unable to do at this time?

Computer based analysis, such as vulnerability analysis across landscapes, regions, and from different projects.

Establish the relative importance of heritage resources. (I don't really want to get into this).

Easily detect when risk to a resource changes.

Most important part of the process: continual process improvement. Agile/Lean

Roots of the problem:

mismatch between modes of representation and nature of what we are protecting (points and polygons, vs. context, experience, data.

inability to combine data. Cannot do longitudinal, or landscape/regional based analysis.

lack of metadata. Partly caused by problem oriented approach, need for efficiency, the inventory approach noted above. Metadata vs. data: depends on who you are. When you practice archaeology, you must collect for a myriad of stakeholders and problems. Old data is amazing in this regard (pre-computer).

Lack of knowledge about the state of knowledge: i.e. survey. We have little basis to understand how well an area has been studied.

inventory based approach rather than modeling. (Perception that computer data are pointers to the “real” data, i.e. reports, artifacts, sites, rather than the data itself being important).

(Digital preservation.?). This is also related to a lack of grappling with the knowledge that the archaeological landscape is constantly changing.

My contributions to these problems:

I will predominantly focus on geospatial representation. This is the most fundamental issue at present. I believe many of these problems can be solved by adapting archaeological praxis to a more meta-data rich approach. New technologies provide the opportunity to record richer metadata in the field without an increase in the time, difficulty, or expense of archaeological work. Commonly used concepts like “sites” require that the components that went into their determination also be recorded and All archaeological work should contribute to a general model of the archaeological universe. As an example, I will provide a model of how to conduct both archaeological surveys and excavations in such a fashion, preserve their metadata through transformation to different knowledge systems, and represent it to stakeholders meaningfully. I will also explore how to incorporate data collected under different paradigms into such an approach.

Specific outputs:

- survey recording proposal
- excavation recording proposal
- a proposal for changing “inventories” to digital knowledge repositories.
- a model of how to present “state of knowledge” information to stakeholders.
- a model of how to present the location of archaeological remains to stakeholders.

Chapter 1: Introduction

Chapter 2: Foundations (Prolog, Charter, Theory)

Chapter 3: Current Practice and Systems

Chapter 4: Analysis (Model of adaptation, shortcomings)

Chapter 5: Solutions 1 (sensor-path survey recording)

Chapter 6: Solutions 2 (semantic crowd-sourced excavation recording)

Chapter 7: Solutions 3 (automated data collection)

Chapter 8: Presenting Data (knowledge storage, decision support systems)

Chapter 9: Example (Petroglyph Point?)

Chapter 10: Conclusion

This is a concrete paper... everything should be specific

Main points:

- how to combine data sources
- how to assess risk
- how to assess significance
- how to institute monitoring and triggers

Recap of Information Needs

Data Sources

Past work

New research

Site re-visits,

Read SAVS, Hinkel Indicators,

Challenge:

Need for information

uncertainty

how gis meets these, where help is needed

primary research needs:

- how to combine data
- how to monitor (rapid site assessment, computer assessment, )
- input models
- state of knowledge

3 prongs: vulnerability assessment of known resources, ongoing monitoring, ongoing cataloging based on vulnerability of areas

Process:

Inventory, carry out vulnerability assessment sessions, assign ongoing risk management targets, monitor.

While this paper is about information structures and behavior, it is important to remember

that the goal is action. William Lockeretz, a physicist and scholar on sustainable agriculture, says that a lack of information was not the problem during the Dust Bowl of the American Midwest during the 1930s (1978). Instead, the failure lay in not taking action despite the evidence that a problem was brewing.

In the case of climate change, the evidence is overwhelming that hazards are impacting and damaging our cultural resources. A U.S. Geological Survey team found 80 feet of shoreline lost in one year in Beaufort Sea. They documented a historic whaling boat approaching the erosion line, and finally disappearing. (Jones 2008)



*Image courtesy U.S. Geological Survey, (Benjamin Jones) 2008*

The boat's eventual destruction was not a mystery. The erosion rates of the beach predicted its loss. Protection requires action. The critical three actions required of us are:

1. Find resources in at risk areas.
2. Stop damage to these resources if possible, or minimize it if not.
3. If not, document the resource to the degree possible to mitigate loss (convert the physical resource to a curated record).

Secondary non-protective action, such as infrastructure changes and budgeting, should only



be considered as support measures, and they should only be undertaken when they lead to more effective physical action.

Is simply gathering more information the critical need?

What is stopping us from taking effective action? The primary enemy of action is uncertainty. Uncertainty in this context is a sense of doubt that blocks or delays action (Lipshitz & Strauss 1997) or a situation that our past experience (“typification”, in phenomenological terms) cannot encompass, rendering our cognitive skills ineffective (Schütz and Luckmann 1974 via Wilson 1999). Uncertainty can derail consultations by creating unresolvable conflicts, torpedo funding, and hurt the morale of teams by reducing confidence and satisfaction of work .

## Exploring Uncertainty

Uncertainty in this process occurs at many scales and places in the process: in the problem, in the system, in the data, and in the outcomes. For example, at a general level, will the political climate continue to support climate change research? And more specifically, what resources will be important to people in the future?

Information scientist T.D. Wilson says that uncertainty can exist during problem identification, definition, resolution, and delivery stages. Failure to resolve uncertainty in any of these stages can result result in being caught in a recurring feedback loop.

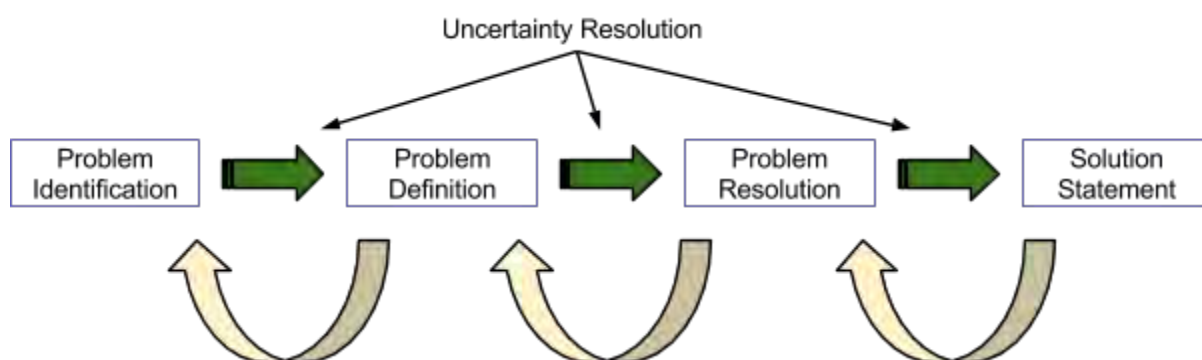


Figure redrawn from Wilson( 1999)

Uncertainty can have both good and bad influences on the process of decision making and subsequent action. Uncertainty alerts us to the potential failure of our own supposed

knowledge/typification and can be useful feedback to our state of knowledge. But uncertainty induces inaction, reduces uptake of systems, and can present too many alternatives which ruin decision making effectiveness. Psychology research shows that in uncertain situations, people are reluctant to think through the implications of each outcome, which leads to poor decision making (Heath & Heath 2007, Tversky & Shafir 1993). A particular issue with uncertainty is this inability to prioritize or compare myriad apparently undifferentiated alternatives. One way to reduce the impact of this situation is to create a decision support system to filter and present relevant information to decision makers, and provide structure to the process required.

## **Decision Support**

Decision support systems are protocols, communications and information systems designed to spur decision making and action. Designing an information system for vulnerability assessment, to help break the logjam of inaction and confusion over response to natural and manmade disasters, including climate change, in our National Parks is vital to our adaptation. Such a system will help avoid sites falling through the cracks of personnel and budgeting shortfalls, and provide us with the ability to prioritize and budget on a regional/national scale.

**{cut out section here of decision support and info sources...fix}**

An effective information and decision support system must engage information seeking behavior in each of these contexts, and provide information relevant to users in that setting.

}

The qualities of these information resources is a source of uncertainty to users of the decision support system. The primary databases, while designed to be useful research tools, are not fully ready to participate in this process. For many years, these have been used to evaluate the performance of managers, rather than as a research tool. This has led to gaming of the system, to the point that large quantities of information have simply been defined so broadly as to apply to almost any resource, and then cut and pasted between entries. Cleaning up this data will be a long-term project.

In the past, researchers have used government databases as finding aids, to point them in the direction of the “actual” information. This search is perhaps best described as Marcia Bates

(1989) as a “berrypicking” approach, where people meander in and out of the information contained in printed records, site reports, the memories of those who carried out the research, or the “original” information contained in the items and resources themselves. While functional for some kinds of research, this approach is not practical for climate change adaptation, which requires parallel evaluation of thousands of sites at one time, in a common reference frame.

Successfully implementing this will require a regional or national GIS dataset. At the moment, data about cultural resources is held in a variety of formats (including paper reports, GIS datasets on personal computers, in state office GIS systems (which range from 3x5 index cards to sophisticated online web mapping systems), and in spreadsheets of coordinates. These all establish some sort of spatial representation of resources, but as it stands they are inadequate and incapable of useful integration. Data must contain better metadata about how their spatial representations relate to the conceptual resource we are protecting.

Archaeological sites, for example, do not have hard boundaries, but represent significant increases in the density of cultural materials. How are the boundaries in GIS data related? At the most outer edge of discovered materials? When the frequency dropped below some threshold? What about point datasets... how does the point relate to the three dimensional resources being represented? Spatial data contained in various datasets rarely agrees. Other issues exist about GIS presentation to stakeholders. Another information need is for predictive models from other fields, such as wildfire predictions, sea level and erosion maps.

User uptake of systems with such exposed uncertainty is poor (Heath & Heath 2007). If people do not trust the information inputs into the system they will not trust the outputs.

Some key uncertainties in this project include:

- Do these data sets really represent all our cultural resources?
- Is the data in the GIS/database reliable?
- Are the predictions of climate change reliable?
- Why don't databases agree?
- How do we measure site significance usefully?

## **Coping with Uncertainty**

Organizational psychologists and decision theorists Lipshitz & Strauss (1997) identify 3 types of uncertainty:

- missing information
- incomplete understanding (including too much information, and conflicting information)
- undifferentiated alternatives

This project encompasses all three of these types, as exemplified earlier. Our goal is to either eliminate it, or remove it as a barrier to action. Many models assume more information is the key. While this may help with missing information, it may add to problems with incomplete understanding, which can occur when we have conflicting information, and merely adding data can increase confusion, as Tversky and Shafir showed.

Information science and decision making literature demonstrate many ways to reduce the effects of uncertainty. One common approach is abbreviated RQP (Cohen 1985):

- Reduce uncertainty where possible (through information addition)
- Quantify remaining uncertainty (statistically)
- Plug outcomes into a formal behavior

This may oversimplify the problem. Quantifying uncertainty is remarkably difficult (if it were easy, it wouldn't be uncertain). In many settings, quantifying uncertainty is nearly impossible, and perhaps useless (Makridakis & Taleb 2009 and Mandelbrot & Taleb 2006). Perhaps most challenging is that the formal behavior in the Plug step is often where most uncertainty is removed, via suppression and arbitrary choice reduction (Lipshitz & Strauss 1997). For example, risk matrices as a formal behavior may present spurious ordering of priorities (Cox 2008).

Lipshitz & Strauss (1997) empirically studied how people coped with uncertainty and presented the RAWFS mnemonic as a more grounded description of possible responses:

- Reducing
- Acknowledging/Assumption base Thinking
- Weighing pros and cons
- Forestalling

- Suppressing

From this list, Reduction, Hedging, and Acknowledging have positive outcomes on decision making for our context.

## **Reducing Uncertainty**

Although designing a decision support system is itself a way to reduce structural uncertainty, through aiding information searching, the system itself must address uncertainty reduction to be successful. Uncertainty is subjective, so it is relevant to a given researcher in a particular moment. It is not an absolute value to be reduced or eliminated. Nonetheless, there are many ways that uncertainty can be reduced in a situation.

- change the system
- wait for things to become more clear
- gather more information
- clarify existing data
- shorten time horizons

Changing the system (i.e. stopping climate change) is the domain of climate change mitigation, not adaptation, as we have defined them. Waiting for things to become more clear is inaction. Resources are lost every day, so waiting for things to become more clear might reduce uncertainty but guarantees failure of our mission.

What uncertainties can be addressed today? A primary uncertainty is that we do not have a good grasp on what cultural resources are held in our lands. Although the National Historic Preservation Act directed federal agencies to survey our lands for resources nearly 50 years ago, to date, we do not have a dataset that shows what areas have been searched. Individual reports of survey projects exist in the State Historic Preservation Offices, but there is no standardized way to represent survey coverage, nor unified data set. An often-heard figure is that 5% of public lands have been surveyed, but the origin of this figure is indecipherable. Without this, it is impossible to assess our state of knowledge about any given piece of land.

A first step to any information system for climate change action is that we must collate the

survey data from the past into a state-of-knowledge map, and commission future surveys in areas of high risk. Future work should include a more sophisticated way of measuring intensity. Even if a percentage figure can be obtained, it is insufficient as a measure. How hard have people looked in that area? Did they dig test pits? Did they use imaging products like ground penetrating radar? How closely did searchers walk together? How experienced were they? Were the weather and vegetation conducive? Data tests from the Pacific West Region have shown that narrative reports from contracted surveys use terms like “intensive” in inconsistent ways. For example, one report from Whiskeytown National Recreation Area called a survey where each person covered 500 acres per day “intensive” while another used the same terminology for 1/100th of that area.

Shortening time horizons is another technique we can implement. At first blush, this seems counter-intuitive. We are often led to believe that the essence of strategic thinking is strategic, long term planning. Indeed, long term planning is important. However, current climate models do not support the twenty year planning cycle used by the park service. The ASMIS database lists the frequency of site assessments by archaeologists. The average time between visits (as of 2010) was thirty years, a number that is clearly outside our ability to predict impacts. We need to reduce this time dramatically, and also speed our ability to react, such that intervention can be dispatched without a multi-year planning cycle. Many cultural resource projects spend years in the funding project. Again, outcomes many years out are too uncertain for this to be our *modus operandi*. Improving our ability to monitor sites against baselines is vital. Monitoring targets must not be based on destruction of the resource itself, but on some measurable baseline outside. For example, a good monitoring target may be the number of feet of land between an eroding coastline and a Native Alaska cemetery, or the temperature of permafrost above a frozen archaeological site. For this monitoring to be effective, though I believe we need to establish what happens when a monitor trigger is reached, such that action is inextricably linked to the monitoring target.

Monitoring need not be expensive. Some threats can be monitored via GIS tools. For example, we can watch for changes in vegetation through satellite imagery such as ASTER and Landsat, while LIDAR (laser scanning from airplanes) can measure encroaching erosion. For this to be effective, decision makers must have easy access to this data in a console format, rather than expecting them to conduct analysis on a rolling basis. Ideally, these data will be

published as a service from their respective subject matter experts, as flood zones are published by the Federal Emergency Management Administration (FEMA).

Comparing our resources to these GIS models also requires modifications to our representations. Currently, our GIS systems model resources in a very Western cartographic tradition-centric way. We use the cartographic primitives of points, lines, and polygons, while these may not represent the resources in ways that our stakeholders consider appropriate. As a first attempt, we can realize that a given resource may have many representations, including multiple boundaries relevant to different temporal scales, and may include things like viewsheds and soundscapes.

## **A Basic Plan**

Convening a risk assessment:

Scale: should it be national, regional, or park based?

Regional at least... otherwise cannot rank funding.

Style: initial scenario planning, establish relevant monitoring targets

Need to talk about targets... problem with symbolic ones.

## **Concrete Triggers**

Triggers are needed to cognitively avoid the “frog in a slowly heating pot” scenario.

How do we know that preservation action is needed?

In the current day, triggers for action may come from a variety of sources:

official site condition assessments

unofficial site visits by NPS staff (maintenance, rangers, etc) and then reported to CR staff

reports by the public

This organic process suffers from a number of weaknesses.  
the resource itself is used as the indicator. In other words, damage is stopped when it threatens

Weakness: use of material itself as indicator.

In this fashion, some portion of the resource must be lost (sometimes a significant portion of it). Thresholds required before action must be those of buffers around resources, or those that alert us to the need for action -before- any of the attributes that make a resource valuable are lost.

Short notice:

Given our funding structures, we need large quantities of time to prepare responses.

Non-quantifiable

It is hard to present to park superintendants, other folks, that a need is pressing and requires response.

Proposal:

All resources should have a monitoring plan for all indicated threats.

## **Acknowledging and Hedging Uncertainty**

“The history of Western science confirms the aphorism that the great menace to progress is not ignorance but the illusion of knowledge.” D. J. Boorstin, "Cleopatra's Nose" (1995)

All information is inherently uncertain (Couclelis 2003). Not all uncertainty can be eliminated in a decision support system. We should not seek to remove it entirely from the view of decision makers, even if that were possible. Biases and non-creative thinking are endemic and problematic unless uncertainty is known and explicitly communicated (see Heuer 1999). Uncertainty is also a key element in promoting creative thinking (Wallerstein 1998).

How can we acknowledge uncertainty, while preventing the paralysis of inaction? There are



some quantitative ways to express uncertainty yet still arrive at differentiated results. The previously mentioned risk matrix may hide too much from the user. One possibility is the Minimax regret approach (Loomes and Sugden 1982), a quantitative style of scenario planning where consultees are presented with potential futures, and evaluate the best and worst possible cases for a given scenario.

An even more useful approach may be hedging, where we link outcomes to uncertainties, so that decisions may automatically be changed when estimations of uncertain inputs change, without explicit user input. Thus, we might decide to excavate a site in the path of erosion next year, but when a new model shows that erosion will subside, that excavation can be rescheduled for a later year. This kind of flexibility is closely related to monitoring abilities.

## **Extraordinary Events, Uncertainty**

Uncertainty that can be measured is appropriate for risk assessment, but events outside measurable likelihood require other approaches.

(Lövkvist-Andersen 2004 TK)

Best is scenario planning.

## **Implications for design**

Although some uncertainty is inherent, information systems and future research must be capable of (and accomplish) reducing uncertainty. Perceptions of uncertainty inherent in the data can be counterproductive to action. A useful system must preserve and present uncertainty in a processed and understandable way. A short synopsis of one such system would include:

- Identification of exposure to hazards done automatically for certain GIS-friendly things
- Warnings of high risks sent to agencies and stakeholders via automatic email reporting
- Susceptibilities and significance qualitatively assessed, with ranges established by Minimax regret functions

- Processed through Bayesian or Risk Matrices to yield priorities
- Monitoring to reduce consequences of uncertainties
- Establishing areas of high uncertainty as targets for future research

A problem with effective prevention programs is that, if they are successful, no recognition results and they are seen as needless. Waiting for tragedy to strike and then intervening is far more effective for gaining acknowledgement (Taleb 2011). However, a system that helps lay out the problems of the future in a way that promotes understanding, and can track our efficacy at improving it, can provide the best of both worlds.

I have analyzed our current information systems and identified key shortfalls (see Paper X). I have created a unified data structure with recommendation for presentation that helps both reduce and acknowledge uncertainty, while providing access to relative risk from climate change hazards to decision makers in the park service and to stakeholders in consultation. This system is detailed in Paper Y. I have also developed several recommendations about our field data creation and representation practices for spatial data, which can be found in Paper Z.

# Cydoemus Project Proof-of-Concept Report

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## Project abstract

The Cydoemus suite of tools helps archaeologists work with uncertain geospatial data. All forms of spatial data recording, such as GPS, geodetic survey, or digitizing from maps, have associated uncertainty. Cydoemus processes and represents that uncertainty for users conducting analysis or visual assessment of archaeological maps. The tool reads from data that has been saved in the Federal Geodata Standard Committee standard format for cultural resources.

## **Background Discussion**

In its history, archaeological research has been carried out through numerous paradigms and has experienced sweeping changes in recording technologies. Archaeologists commonly assert that most archaeological research is destructive. As such, data gathered in the past cannot be re-gathered, as spatial structure is usually destroyed in the act of excavation. It is critical that we be able to combine data excavated through various techniques and approaches, if we are not to start over with each new project. Databases in universities and government offices everywhere are full of inconsistent, incompatible data. For that reason, this project was named for Cydoemus, the Greek god of confusion.

One major issue with combining such legacy data is that today's Geographical Information Systems approaches tend to represent all data the same... that is, as dots on a map, or crisp polygons. This representation, which is used both visually and for analysis, masks potentially enormous differences in the uncertainty of the data. For example, Global Navigation Satellite Systems (such as GPS), create statistical assays of locations relative to a global grid. These values may vary dramatically from minute to minute, and place to place, depending on local reflections, the conditions of the ionosphere, etc. These may range from approximations down to the centimeter, or up to hundreds of meters. The locations of artifacts are commonly recorded by unit or quad in excavations, yielding expected locations within a meter or 25 cm, respectively. Very old sites may have locations recorded only by the Public Land Survey System (PLSS). A site recorded to the quarter section is known to only within a quarter mile area. Yet GIS will store and display all of these as points. Users can zoom down to scales of fractions of a centimeter, yet all these points appear and behave the same, as if they were perfect pinpoints. With polygon data it is the same... the edges are perfect and clean. This yields misleading analysis.

There are many sources and kinds of uncertainty in archaeological data. This project is in its infancy, and at this stage, these tools only address measurement error that is normally distributed, such as data from GPS units, Total Stations, or digitized from topographic maps.

## **Technical Description**

There are two primary tools in this package so far. The first processes the open text field specified in the FGDC data standard into a more rigorous data format, and the second takes that data storage and represents it for analytical or visual display.

Text processing:

The cultural resources geospatial transfer data standard contains an attribute field called "SRC\_ACCU". This is a free text field. Within the Pacific West region, I have enforced a loose standard, where people write a distance statement followed by the @ sign, and the confidence interval, stated as a %. Other text data may be written in human readable form. In practice, this has yield a very diverse universe of entries. For example, these entries are all for

archaeology sites in parks:

- 1m@CE90
- +-4m
- 8.1m@unknown, assume 68%(RMS)
- 20.3m@90%, USGS topo
- 7m@95%
- No better than 31.73m@90% (NMAAS for underlying map)
- 2-5 m

Data from most measurement sources is delivered to archaeologists with either no mention of error, or with error expressed as a distance unit and confidence level. Common statistical measures include:

- NMAAS, the old national map accuracy standard from 1947. This standard was used on almost all topographic maps. It cannot be used for digital data, because it is inherently dependent on printed scale. The standard states: “For maps on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error by more than 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, 1/50 inch.” For a 1:24,000 topo map, this equates to a 40 foot error at 90% confidence. <http://nationalmap.gov/standards/nmas.html>
- NSSDA, which replaces NMAAS, is based on a 95% confidence interval. It is statistically more robust and includes horizontal and vertical accuracy statements. Modern topo maps, LIDAR data, and other high quality data sources are given in NSSDA. <http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/capter3>
- CEP, circular error probable, is a common expression. Originally defined for estimating military weapons accuracy, many consumer grade GPS units estimate error in this way. CEP is expressed as a distance, within which the actual point of measurement is 50% likely to be. Some GPS manufacturers do not specify their confidence value, asserting that this is a trade secret.
- More sophisticated GPS may report data at one standard deviation, NSSDA, or at a user defined confidence. Trimble post-processing software, for example, allows the user to specify this value.

All these values can be converted between each other (although not perfectly), because they are all statistical measures based on a normal distribution. Published conversion tables exist<sup>1</sup>, usually giving values for rms, 67/68%, and 98% confidence, in the form of multipliers. However, many of the archaeological data formats listed above are not found in the tables, which are quite coarse. The tables originate in a cumulative density function,  $p = \text{ChiSq}(R^2, 2)$  where p is probability, and 2 is the degrees of freedom. R is the radius of the circle containing the cumulative probability, as such it is a multiplier, relating standard deviation to

---

<sup>1</sup> “GNSS Accuracy – Lies, Damn Lies and Statistics.” F. van Diggelen, GPS World, Vol. 18, No. 1. (January 2007)

other probabilities.

Python includes a chi square calculation, but it is inside the SciPy libraries. It also works by converting critical values to probabilities, and cannot be reversed. A goal of this project is to work strictly within the standard libraries supplied with an ArcGIS installation. SciPy is not included. To accommodate both of these issues, I have pre-generated a dictionary of values, interpolating to the 0.001% probability level, along with its inverse that can be used without SciPy. These are saved as pickled objects (ordered dictionaries). An ASCII file also contains ArcGIS standard reclass data, for converting rasterized distances into probabilities. In the includedExtras directory, the script chi2Generate.py allows the user to generate these dictionaries and ASCII files using their own values (if they have SciPy installed).

There is an existing XML standard for describing uncertainty, found at <http://www.uncertml.org/>. This standard allows for distributions and samples to be defined using a controlled vocabulary and public namespace. The FGDC cultural resources data standard allows for user extension beyond the required fields, so I have added an additional text field to store this XML declaration. While some simple measures, like standard deviation, could be stored as double precision numbers in an attribute field, this would be less extensible in the future, when we hope to add other uncertainty measurements in a more complex way.

The addXML script creates this XML declaration by parsing the SRC\_ACCU and MAP\_METHOD fields of FGDC compliant datasets. It searches for common symbols, such as @ and % to choose distance and confidence numbers. This could be made more powerful by importing text processing tools. Users may pre-process the data to make this process more effective. This combination of distance and p-value are converted to one standard deviation using the cumulative density function lookup table. The XML uncertainty standard calls for variance, so the standard deviation is squared.

The representation script reads this XML file and extract the element tree, and extracts the distribution type and values. So far, this only includes normal (gaussian) distributions. It then iterates through the input file, and creates rasters of distance from each feature. These distances are divided by the standard deviation, and the resulting value is converted to probability using the reverse chi square lookup table created by chi2Generate.py.

These rasters are then combined using the fuzzy overlay tool (although it could as easily be done with mosaic, if other output controls are desired).

## Algorithm/s (pseudocode)

### Text Processor

1. Imports etc
2. Get from user (via toolbox dialog)
  - a. the file to be processed
3. Unpickle the dictionary objects
4. Add the XML uncertainty field, if it doesn't exist already
5. Define functions for
  - a. finding the distribution, from the Map\_Method (for now, all are Gaussian)
  - b. find the probability value from the raw text fields and convert using the chi dictionary
  - c. create a properly formed xml declaration and write it to the file
6. Create an updatecursor and iterate through rows, using functions to write the field.

### Representation Script

1. Import modules
2. Get from user
  - a. the feature class to be processed
  - b. the workspace
  - c. the intended resolution and scale of output
  - d. the spatial reference (UTM zone)
  - e. the desired probability levels for multiple buffer rings
3. Set up the workspace and check out licenses
4. Make a working layer of the process layer and project it (the FGDC standard is in a geographic coordinate system, which is problematic for this analysis)
5. Calculate the desired pixel size and set raster padding necessary to prevent edge effects
6. Define function for creating extents in the workspace
  - a. from an existing raster
  - b. from the centroid of a geographical feature
7. Make a raster layer of the features, and use it to assign the default raster space
8. Initialize lists of the files created to use for merging and deleting
9. Create a search cursor and iterate through the rows
  - a. parse the xml error and extract the underlying variance
  - b. create a layer of just this feature
  - c. calculate the size of raster needed to fully cover the uncertainty field of this feature
  - d. create a distance raster from this feature
  - e. calculate the distance raster

- f. convert distance to std deviations
  - g. convert to p values using a reclassify ASCII table
  - h. create polygon buffers (multiple rings) for this feature, using user defined intervals and save as a feature
10. Combine the probability rasters
  11. Combine the polygon buffers
  12. Add attributes of original polygons for easier use, labeling and identification
  13. Delete leftover files

### Chi Table Generator

1. Imports
2. Define a function for pickling objects
3. Create ordered dictionary to hold a chi square table (for fast indexing using bisect)
4. Loop through a numpy space from approximately p 0.5 to p 0.9999 (chi 0.5 to 4.1)
  - a. calculate the cumulative density function for this chi value and save as a dictionary pair
5. Pickle the dictionary
6. Invert for reverse lookup (could be done with scipy, but this is convenient for machines without it installed) and pickle
7. Convert to an ESRI standard ASCII text file for reclassifying and save



## Code

```
#-----  
# Name:    ChiSq Generator  
# Purpose:  
#  
# Author:  jflaming  
#  
# Created: 15/03/2013  
# Copyright: (c) jflaming 2013  
# Licence: <your licence>  
#-----  
  
import scipy.stats, pickle, collections  
import numpy as np  
  
#define a function for pickling objects directly to files  
def saveobj(obj, file):  
    with open(file, 'wb') as output:  
        pickle.dump(obj, output, pickle.HIGHEST_PROTOCOL)  
  
#create a chi square table cumulative density function table for use in uncertainty reverse  
probability calculations  
#for rVal = 0.5 to 4.0 using integers for ease since Python doesn't iterate decimals easily  
  
chiDict = collections.OrderedDict()  
#chiDict = {} #initialize the dictionary  
  
for rVal in np.linspace(0.5, 4.1, num=500):  
    #rVal = i/100.0  
    pVal = scipy.stats.chi2.cdf((rVal**2), 2)  
    chiDict[pVal] = rVal  
  
#pickle the dictionary for use in other tools  
saveobj(chiDict, 'chiDict.pk')  
  
#invert dictionary values for lookup later  
probDict=collections.OrderedDict((value,key) for key,value in chiDict.iteritems())  
  
saveobj(probDict, 'probDict.pk')  
  
#remap object for reclassifying rasters to probabilities
```

```

remapList = []
prevKey = 0.0

for key,value in probDict.iteritems():
    tempList = []
    tempList.append(prevKey)
    tempList.append(key)
    tempList.append(value*100)
    remapList.append(tempList)
    prevKey = key

saveobj(remapList, 'remapList.pk')

#for i in remapList:
#    line = str(remapList[i][0]) + " " + str(remapList[i][1]) + " : " + str(remapList[i][2]*100)
#    + "\n"

with open('reclassProb.rmp', 'w') as f:
    for i in remapList:
        line = str(i[0]) + " " + str(i[1]) + " : " + str(int((i[2]*100))) + "\n"
        f.write(line)
    f.closed

#-----
# Name:    addXMLdata.py
# Author:  jflaming
#
# Created: 02/12/2013
# Copyright: (c) jflaming 2013
#-----
"""
open the feature class, add xml field if not present, then iterate through and create
"""
#TODO unit conversion?

#opening declarations
import arcpy, pickle, re, collections
import xml.etree.ElementTree as ET
import numpy as np
from xml.etree.ElementTree import Element, SubElement, tostringing

```

```

#get data from user
#-----
#if you wish to run this scrip outside the toolbox comment this line and uncomment
following
inputFeat = arcpy.GetParameterAsText(0)
#inputFeat = r"P:\Project\CR_PWRO_secure.gdb\small_test"

#Load data from files
#-----
#the chi square conversions table location:
chiDict = pickle.load(open('chiDict.pk', 'rb'))

#add the xml field if it does not exist
try:
    arcpy.AddField_management(inputFeat, "xmlUncert", "TEXT", "", "", 4000)
except arcpy.ExecuteError:
    arcpy.AddError(arcpy.GetMessages(2))
except:
    arcpy.AddError("An error occurred while adding the xml field.")

#create functions for text processing input data
#-----
def findDistr(Map_Method, SRC_ACCU):
    #return distribution, either uniform or gaussian or whatever...
    #at this point, only Gaussian supported, but in the future uniform pixel based dist will be
    added
    if "GPS" or "Total Station" or "Theodolite" or "Digitized" in Map_Method:
        distr = "NormalDistribution"
    else:
        distr = "NormalDistribution" #assume normal if unspecified
    return distr

def findStdDev(SRC_ACCU):
    #find the stated error distance
    try:
        distStr = (SRC_ACCU.split("@"))[0] #find the stated distance error
        p = re.compile("[^0-9.]") #the regex for getting rid of everything but decimal nums
        distVal = re.sub(p, "", distStr)
        distVal = float(distVal)
    except:

```

```

    distVal = 400 #assign 400 meters of error if unknown, approximately 1/4 section

#find the stated error confidence level
try:
    pStr = ((SRC_ACCU.split("@"))[1]).split("%")[0] #find the stuff between @ and %
    pVal = re.sub(p, "", pStr)
    pVal = float(pVal)/100
    print chiVals, "chiVal"
except: #if text processing has failed, assign a default 50%, as this is most common, and is
conservative
    pVal = 0.50

#find corresponding chi value
chiVal = chiDict[pVal] if pVal in chiDict else chiDict[min(chiDict.keys(), key=lambda k:
abs(k-pVal))]

#use the chi value multiplier to get to RMS
#to get to std deviation, must multiply times 1.51
stdDist = (distVal/chiVal) * 1.51
return stdDist

def createXML(distr,stdDev): # create XML statement of the uncertainty
    attrib = {'xmlns:un':"http://www.uncertml.org/2.0"}
    root = Element("un:"+distr, attrib)
    child = SubElement(root, "un:variance")
    child.text = stdDev
    return tostring(root)

#iterate through rows and write xml def
#-----
with arcpy.da.UpdateCursor(inputFeat,["Map_Method", "SRC_ACCU", "xmlUncert"]) as
cursor:
    for row in cursor:
        distr = findDistr(row[0], row[1])
        if distr != "UniformDistribution":
            stdDev = findStdDev(row[1])
        else:
            stdDev = 0
        distVar = str(stdDev**2) #xml standard uses variance not std dev
        xmlDataTxt = createXML(distr,distVar)
        row[2] = xmlDataTxt
        cursor.updateRow(row)

```

```

#-----
# Name:    representXML.py
# Author:  jflaming
#
# Created: 02/12/2013
# Copyright: (c) jflaming 2013
#-----

#opening declarations
import arcpy, pickle, collections
import xml.etree.ElementTree as ET
from arcpy.sa import *

#get data from user
#-----
"""
workspace = r"P:\Project\CR_PWRO_secure.gdb"
inputFeat = r"P:\Project\CR_PWRO_secure.gdb\testDiscTrail"
spatialRef = arcpy.SpatialReference("WGS 1984 UTM Zone 10N")
reclassFile = r"P:\Project\cydoemus\reclassProb.rmp"
desiredResolution = 300 #in dpi
desiredScale = 24000 #1 to x is implied
buffProbs = [0.78, 1, 1.85] #CEP, 1 std dev, 98% probabilities... user can hardcode for
different
"""
workspace = arcpy.GetParameterAsText(0)
inputFeat = arcpy.GetParameterAsText(1)
spatialRef = arcpy.GetParameterAsText(2)
reclassFile = arcpy.GetParameterAsText(3)
desiredResolution = float(arcpy.GetParameterAsText(4)) #in dpi
desiredScale = float(arcpy.GetParameterAsText(5)) #1 to x is implied
buffProbs = [0.78, 1, 1.85] #CEP, 1 std dev, 98% probabilities... user can hardcode for
different

#arcpy stuff
#-----
arcpy.env.workspace = workspace
arcpy.CheckOutExtension("Spatial")
arcpy.env.overwriteOutput = True

```

```

arcpy.env.outputCoordinateSystem = spatialRef
desc = arcpy.Describe(inputFeat)

#make a working layer
arcpy.MakeFeatureLayer_management(inputFeat, "inputFeatLyr")

#project the working layer
arcpy.Project_management("inputFeatLyr", "inputFeatLyrProj", spatialRef)

rastPad = 4000 #default amount to add to rasters to avoid edge effects, in meters

#1 pixel in desired out put will represent how much of a meter?
pixelSize = ((1.0/desiredResolution)*0.0254 *(desiredScale))/2 #meters per pixel, factor of
safety of two for clean display

def setExtentsLyr(lyr, rastPad):
    #determine extents and write to environment
    lyrData = arcpy.GetRasterProperties_management (lyr, "TOP")
    yMax = str(float(lyrData.getOutput(0)) + rastPad)
    lyrData = arcpy.GetRasterProperties_management (lyr, "LEFT")
    xMin = str(float(lyrData.getOutput(0)) - rastPad)
    lyrData = arcpy.GetRasterProperties_management (lyr, "RIGHT")
    xMax = str(float(lyrData.getOutput(0)) + rastPad)
    lyrData = arcpy.GetRasterProperties_management (lyr, "BOTTOM")
    yMin = str(float(lyrData.getOutput(0)) - rastPad)

    extent = xMin + " " + yMin + " " + xMax + " " + yMax
    arcpy.env.extent = extent

def setExtentsXY(x,y,rastPad):
    yMax = str(y + rastPad)
    xMin = str(x - rastPad)
    xMax = str(x + rastPad)
    yMin = str(y - rastPad)

    extent = xMin + " " + yMin + " " + xMax + " " + yMax
    arcpy.env.extent = extent

# Make a layer from the feature class
arcpy.FeatureToRaster_conversion("inputFeatLyrProj", "CR_ID", "rasterFeatures",
pixelSize)

```

```

#set default extent to the feature layer
setExtentsLyr("rasterFeatures", rastPad)

rastersCreatedList = []
buffersCreatedList = []

#iterate through the features and process
#-----
with arcpy.da.SearchCursor("inputFeatLyrProj",["xmlUncert", "OBJECTID", "SHAPE@X",
"SHAPE@Y"]) as cursor:
    for row in cursor:
        xmlError = ET.fromstring(row[0])
        xmlVar = float(xmlError[0].text)
        stdDev = xmlVar**(0.5)
        query = "\ "OBJECTID\"="+str(row[1])

        arcpy.MakeFeatureLayer_management("inputFeatLyrProj", "lyr", query)

        #calculate size of raster
        #p value of .9999 is 4.1 * std dev, so 10 is safe for both directions

        maxDist = stdDev * 4.1
        if desc.shapeType == "Point":
            setExtentsXY(row[2], row[3], maxDist) #for points, set a small boundary around the
point
        else:
            pass #for polygons, use the existing extents (the whole feature class)
        #calculate the distance raster
        outEucDistance = EucDistance("lyr", maxDist, pixelSize)
        #distRastName = "eucdist" + str(row[1])
        #outEucDistance.save(distRastName)    #Save the output

        devRastName = "devRast" + str(row[1])
        devRast = outEucDistance / stdDev #raster of how many std deviations each pixel is
away
        devRast.save(devRastName)
        arcpy.CalculateStatistics_management(devRastName)

        #reclassify to p values
        pRast100 = ReclassByASCIIFile (devRast, reclassFile)
        pRast = 100-(pRast100/100) #convert back from long int to p value and invert for
probability of membership
        pRastName = "prob" + str(row[1])

```

```

pRast.save(pRastName)
rastersCreatedList.append(pRastName)

#create polygon buffers
buffersName = "polyBuffers" + str(row[1])
distances = []
for i in buffProbs:
    distances.append(i*stdDev)
arcpy.MultipleRingBuffer_analysis("lyr", buffersName, distances)
buffersCreatedList.append(buffersName)

#combine rasters
setExtentsLyr("rasterFeatures", rastPad) #so the last loop doesn't prevent merges from
including all features

rastersCreated = "" #initialize the list required for mosaic tool

for i in rastersCreatedList:
    rastersCreated = rastersCreated + (i) + ";"

arcpy.MosaicToNewRaster_management(rastersCreated,workspace,
"cydoemusProbRaster", spatialRef, "32_BIT_FLOAT", pixelSize, "1", "MAXIMUM")

#combine buffers
arcpy.Merge_management(buffersCreatedList, "allBuffers")

arcpy.SpatialJoin_analysis("allBuffers", "inputFeatLyrProj", "cydoemusBufferRings")

#delete junk
for file in rastersCreatedList:
    try:
        arcpy.Delete_management(file)
    except:
        pass

for file in buffersCreatedList:
    try:
        arcpy.Delete_management(file)
    except:
        pass

try:

```



```
Delete_management("inputFeatLyrProj")
```

*except:*

*pass*

## **User description**

### Software Required:

The Cydoemus suite of tools was written for ArcGIS 10.1. It may fail on 10.0 and earlier, due to the construction of search cursors. It does not require SciPy, but it is required if you want to create your own probability density lookups or reclass tables. A Spatial Analyst license is required.

### Data Required:

Cydoemus assumes that your data adheres to the FGDC geospatial data transfer standards for cultural resources and is stored in a file or SDE geodatabase. It may well apply to other kinds of data, especially those within the U.S. Department of the Interior's standards. Data quality out will vary depending on the effort that has gone into creating these datasets. In particular, how well the SRC\_ACCU field has been filled out. Cydoemus prefers data in this field to be of the form "xxm@yy% confidence". Extra text will be ignored. Data lacking in one of these values will be given conservative defaults, but may interfere with suitability.

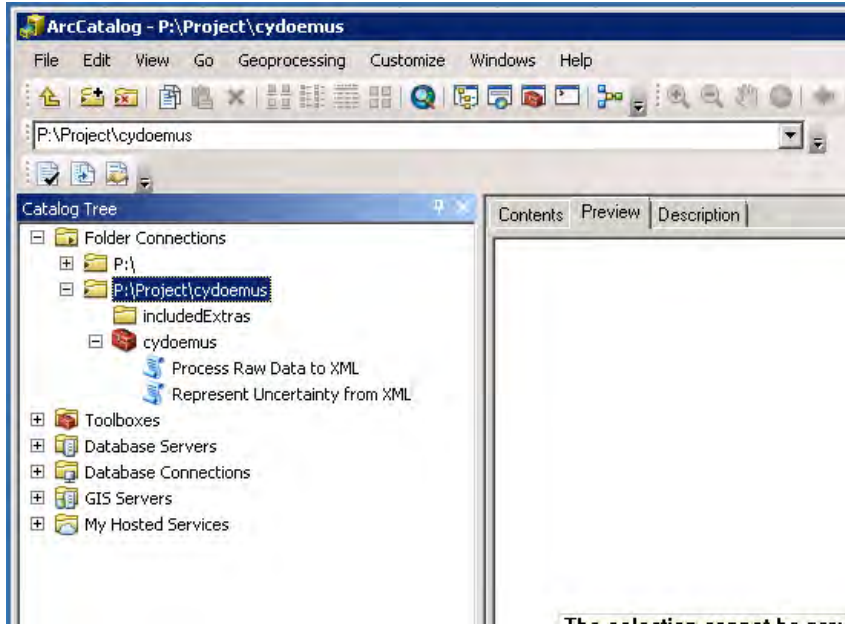
NOTE: Do not store data on a network drive! Due to the heavy disk access required by this script, using a network share to store the workspace and data will slow performance by 2 to 5 times. It is common for the scripts to take over a minute to process each feature... this can take many hours to complete. Consider processing data in small chunks, if this is a problem.

### Hardware Required:

This tool is dependant on a very large number of calculations per feature input. Performance can be quite slow, perhaps hours for large datasets (i.e. thousands of features). Data should be stored locally, not on a network drive, to maximize speed (see above), and a fast computer is suggested.

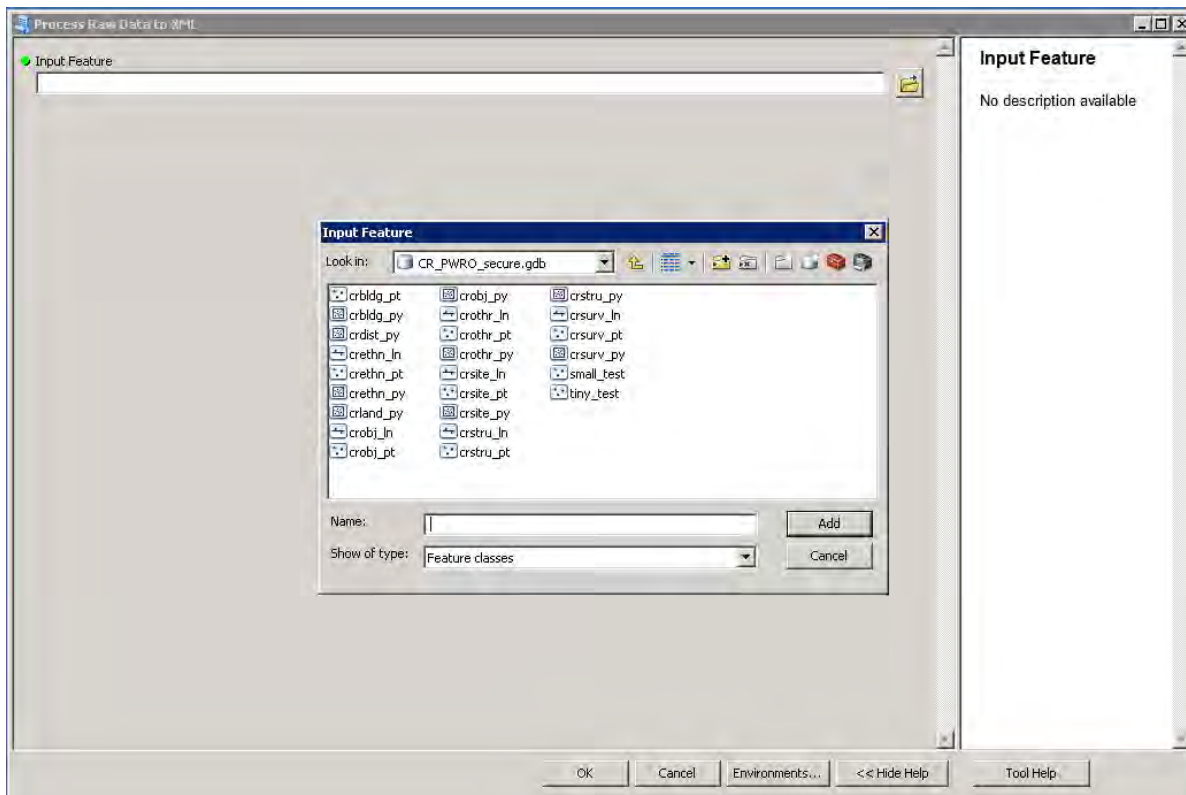
### Installation:

To install, simply unzip the Cydoemus.zip file in a convenient location. Inside you will find the Cydoemus toolbox and associated files.

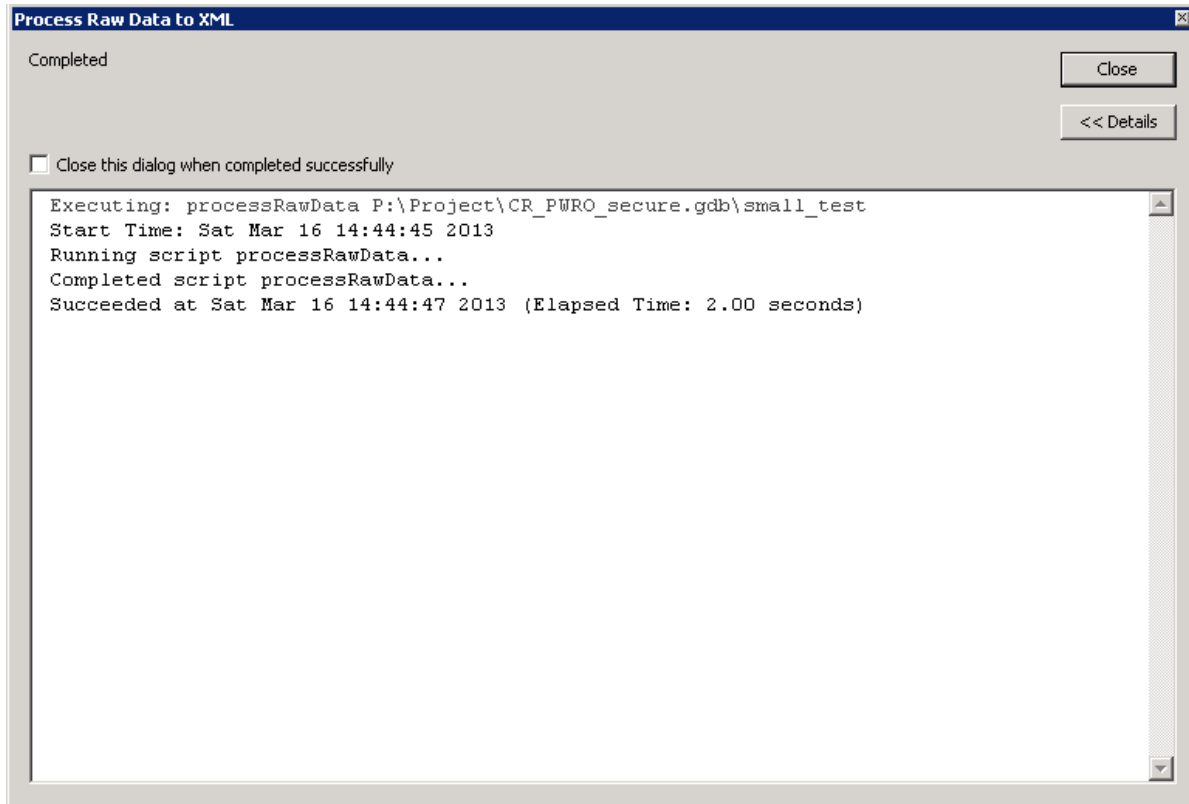


Usage:

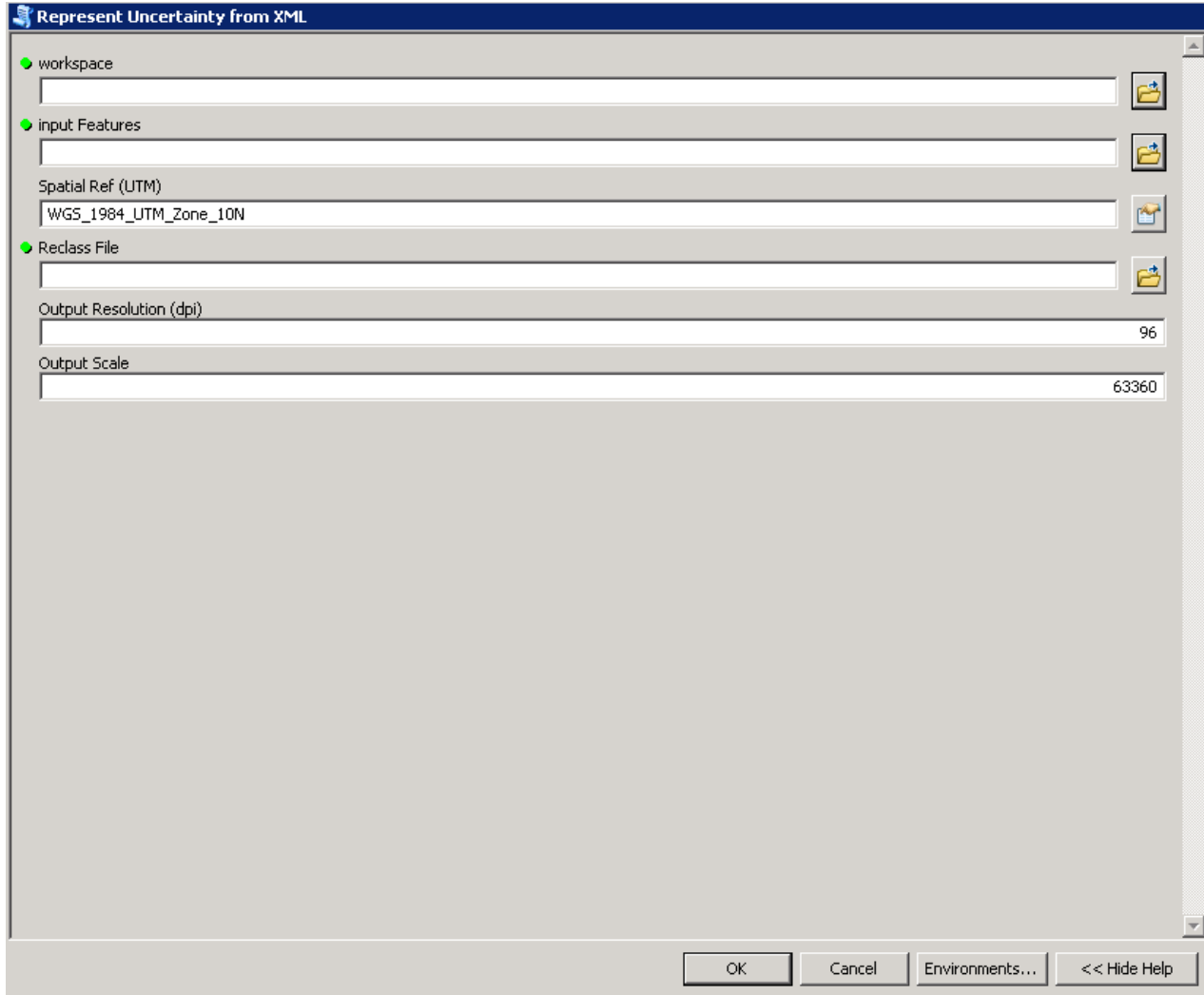
Using ArcCatalog, browse to the location you unzipped Cydoemus. Open the toolbox. You will need to run the “Process Raw Data to XML” tool first. Launch it and choose the feature class you wish to process. You may need to direct the script to the location of the chiDict.pk file as well. By default it is in the Cydoemus toolbox directory.



After the data has been processed, in ArcCatalog, check the feature class, and you should find that a new XML Uncertainty data field has been added and populated. You may need to edit the SRC\_ACCU field to add something like “10m@90%”, if you do not have correct values. Be sure all units are in meters. You can also directly edit the XML data, either as text, or using an XML editor.



To represent this graphically or for analysis, go back to the Cydoemus toolbox and open the Represent Uncertainty from XML tool.



Fill out the dialog box for the parameters. Workspace should be a geodatabase, preferably local.

Input features may be point, line or polygon feat classes, that have already been processed with the Process Raw Data to XML tool. The Spatial Ref should be a projected coordinate system in meters, preferably UTM. The reclass file, by default is named reclassProb.rmp and is located in the Cydoemus tool directory. If you have created a different ASCII remap file, you may specify it here. There are other values you can change by editing the script, if you are an expert user.

For example, the buffer confidence values by default are: CEP, 1 std dev, and 98% probabilities. You could edit these to include a 95 or 99 percent ring, for example.

Output resolution is the dot(or pixel) per inch of your expected output device. For example, most printers are around 600 dpi, and most screens are 96 dpi. You can also enter the expected output scale. The 1: part of the scale is implied. For a 1 inch to a mile scale (1:63,360) for example, enter 63360 for the scale. Enter these values helps the raster outputs be appropriate to the scale of your anticipated use.

After running the tool, you will find two new files in your workspace: cydoemusBufferRings and cydoemusProbRaster. The buffer rings are representations of your input data at the 50% (circular error probable), 68%, and 98% probability levels. The buffers can be understood to mean that there is within the given distance, there is an X percent chance the measured point or polygon lies within that buffer ring. The probability raster indicates an X percent chance that this site is within the measured polygon, or that the point measured is actually located within that grid cell.

Extras:

chi2Generate: requires SciPy installation. This script will generate a fine-grained  $\chi$  distribution table. This table (included with the tool) is used to convert between different confidence levels. If you wish finer (or coarser) values or different reclass lookup values, you may use this standalone tool to generate them.

## Examples

I will demonstrate two examples of using these tools.

Example 1: First, using point data for visual assessment, the scenario is that in National Park Service lands in California, there is an area that was inundated by a rising lake that contained four small archaeological sites.



Were these sites destroyed by the rising water? The GIS map shows three inside the water boundary, and one outside (assuming the water line is correct, itself an uncertainty!). Is this visual inspection reliable given the uncertainty of the data?

These points were digitized from USGS topographic maps at the 1:24,000 scale many years ago. Thus, their published accuracy is NMAAS, a 90% chance that sites lie within 40 ft of the mapped point. Using the Cydoemus processor, that data is parsed as XML, and then rendered as nested confidence intervals and a probability raster.

This is the xml uncertainty declaration for these points:

```
<un:NormalDistribution xmlns:un="http://www.uncertml.org/2.0">
```

<un:variance>244.173187958</un:variance></un:NormalDistribution>

Here is the output using buffer rings:



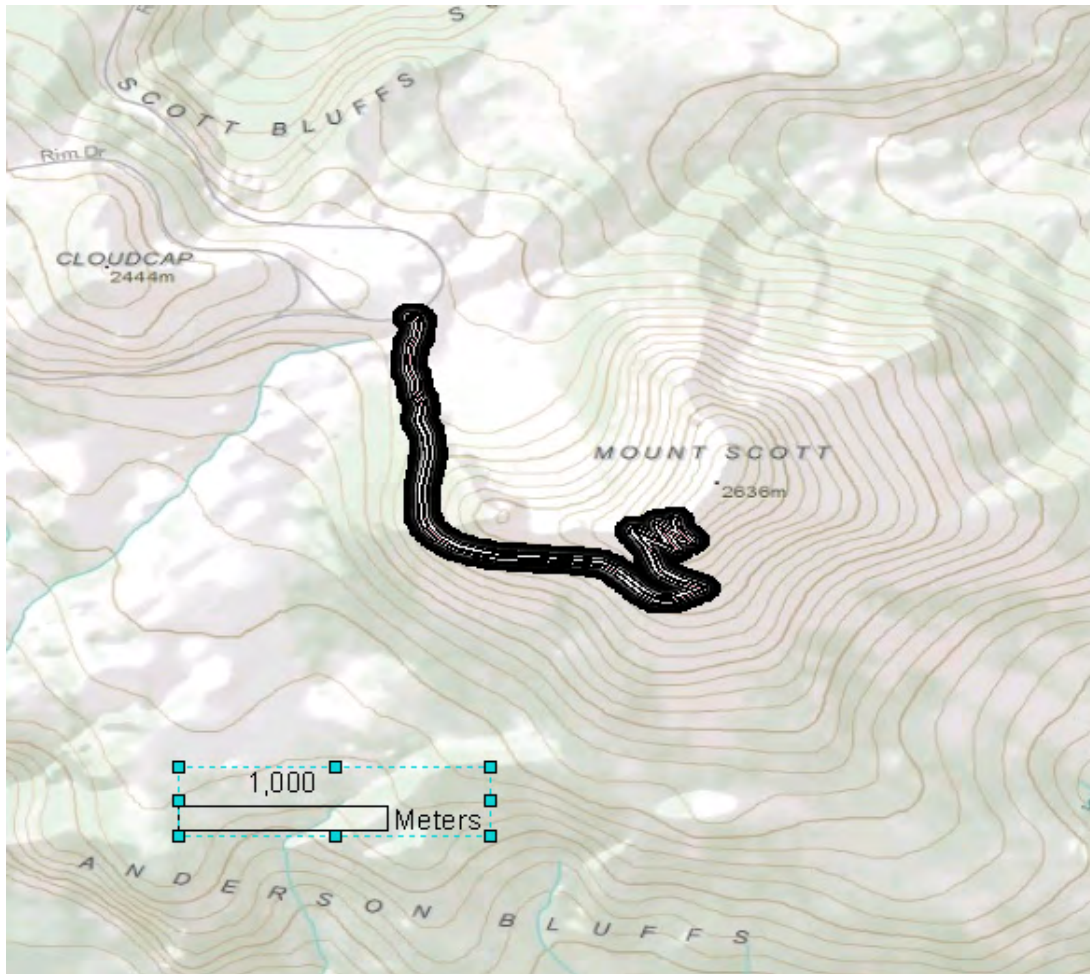
Visual assessment is much easier with this uncertainty representation. The two inner rings represent 50% and 68% probability, respectively, and the outer ring is 98% probability. Compared to the point presentation, in this case we can see that there is some reasonable chance SHA-0203 escaped the water, and the SHA-0202 was actually destroyed. In fact, recent surveys show that all four sites are underwater.

Example two:

As an example of using Cydoemus for analytical purposes, we will look at how uncertainty and imprecise geospatial data can change outcomes of analysis. In Crater Lake National Park, there are many historic trails that probably pre-existed the tourist phase of the area. The Mt. Scott trail has prehistoric sites located nearby, and climbs one to one of the high vista points in southern Oregon, which was once a fire and military lookout. It was re-developed



during the Depression by Civilian Conservation Corps workers, including complex rockwork, drainage features, signage, clearing view areas, vegetation work, etc. How closely do modern trails like this follow historic routes? Did those routes originate from the military? Human footpaths made by indigenous people? Animal trails? Is their routing historically significant, and is this routing at risk? Slope is one characteristic that varies based on mode of transportation. Slope data is also important for characterizing susceptibility to erosion and solifluction. As an example, I took the routes from their recorded data from the National Register.



### ***Mt. Scott Trail***

The Mt Scott trail leads from the historic Rim Drive to the summit of Mt. Scott. I mapped the trails in the park using National Agricultural Imagery Program aerial photos. The center line was digitized, and the width calculated from the imagery, and then centerline was buffered to this width. NAIP images are published with a 6 meter NSSDA (95% confidence). Some of the Mt. Scott trail was mapped using the same method, but the trail was mostly not visible in the aerial imagery, so the trail was digitized from the 1:24,000 USGS topo. The system does not allow for sub-entity confidence, so the entire trail had to be represented at the lower



confidence of the topographic map. The mapped polygon is 10 meters wide. When we apply Cydoemus, at 98% confidence, the possible area of the corridor of the trail is over 60 meters wide. At 99 percent, it is 130 meters.

Does examining this trail at varying confidence levels yield different outcomes for analysis? If we examine the slopes (generated from a 3m digital elevation map) encountered by a person or animal walking the trail, we can see that the values in each confidence band beyond the raw data do change, although perhaps not too significantly. The mean slope does not change significantly. The max slope jumps dramatically, as these lower probability areas at the outer edges are more likely to include cliffs and dropoffs.

Confidence	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
Raw	2981	26341.90	0.25	47.20	46.95	24.81	9.00	73962.80
		98775.5						280376.
50	11178	0	0.25	68.54	68.29	25.08	9.39	00
68	2258	19953.00	2.37	69.29	66.92	25.33	9.29	57184.50
		75402.7						219269.0
98	8533	0	2.01	70.63	68.63	25.70	8.66	0

The raster of confidence can be used as a confidence weight in such situations. In this example, we could weight each slope cell by its likelihood of membership in the cell, to achieve a more defensible estimation of the slope characteristics of the trail.

---

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