Determining soil erosion rates on semi-arid watersheds using radioisotope-derived sedimentation chronology

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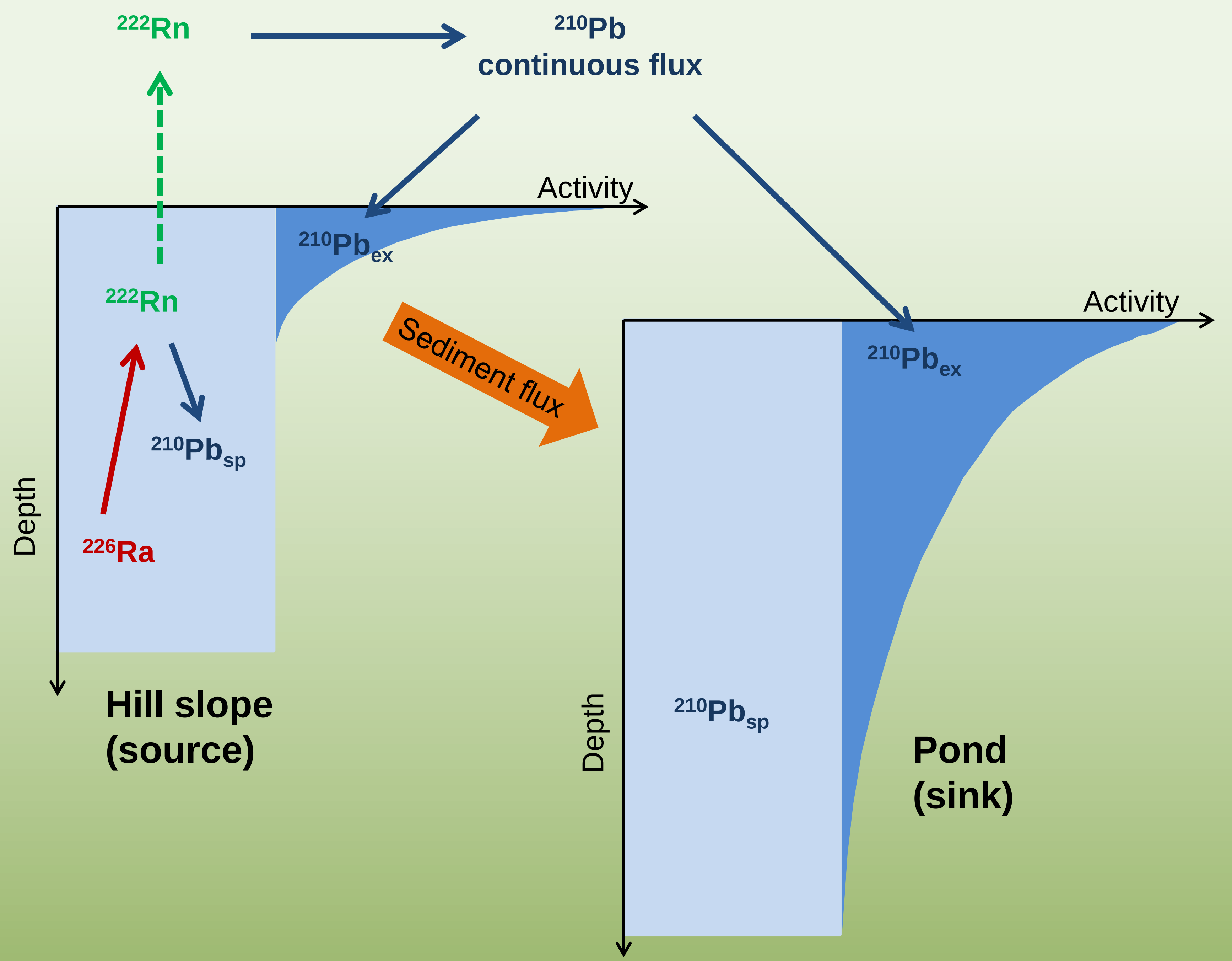
Introduction

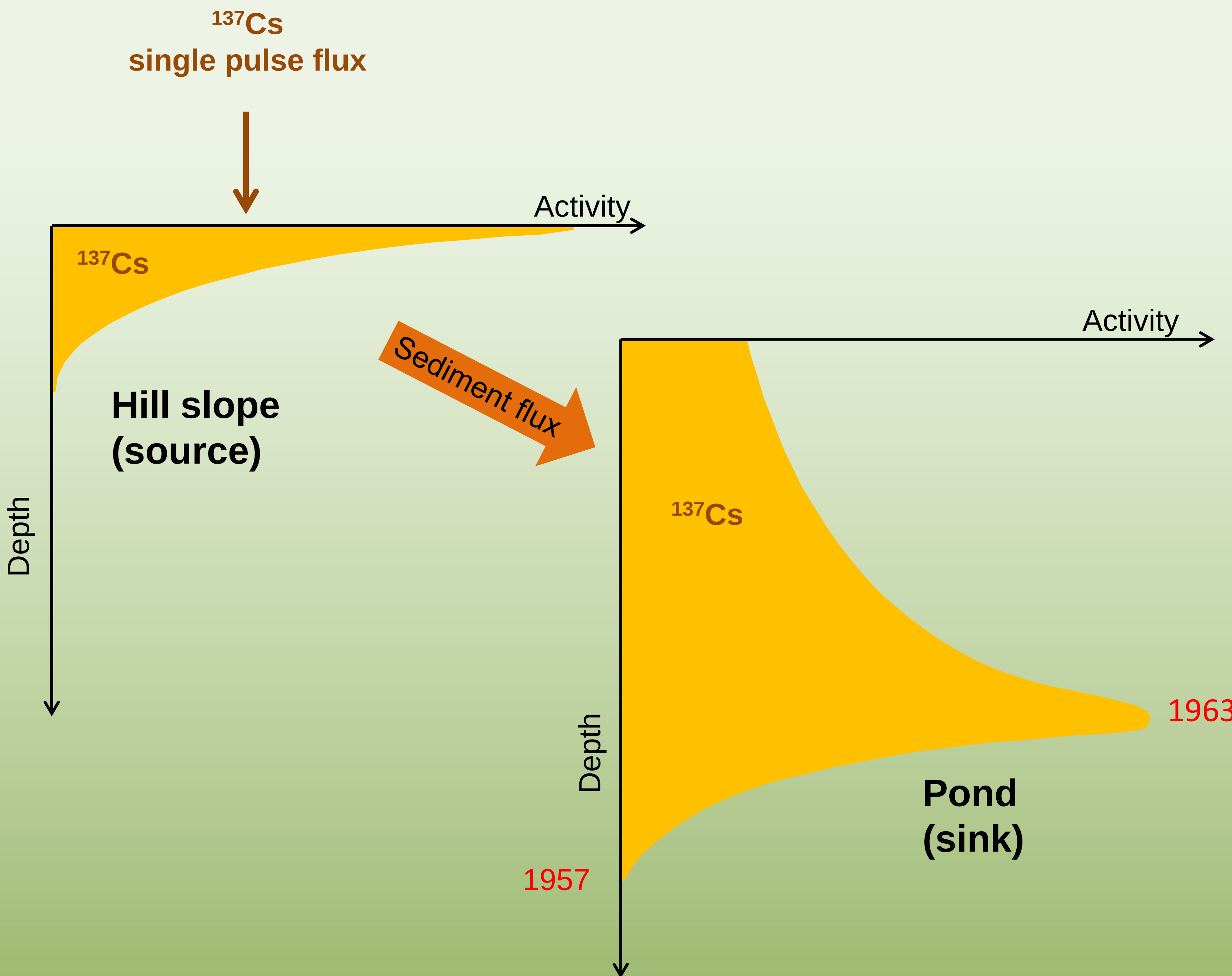
- Sediments stored in depressions, ponds, and lakes contain record of historic erosion processes.
- These records can be interpreted through sediment chronologies.
- Fallout isotopes ^{210}Pb and ^{137}Cs are used for dating recent (0-150 years) sediments.
- Semi-arid environment: high magnitude, low frequency rainfalls; highly variable erosion rates; non-uniform sediment accumulation.
- Isotope method has been used on sites with non-uniform accumulation.
- Stock ponds are common in SW rangelands – opportunity to measure erosion rates on contributing watersheds.

Objectives

- Investigate the applicability of ^{210}Pb and ^{137}Cs method for sedimentation chronology in semi-arid environment.
- Estimate historic soil erosion and sedimentation rates on selected watersheds.
- Determine the effect of management and hydrologic regime on sedimentation and erosion processes.

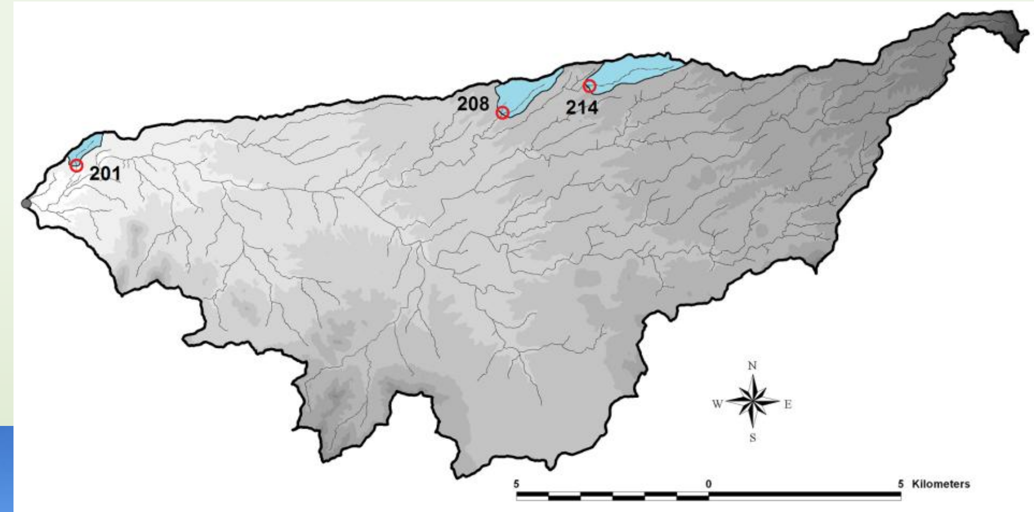


^{222}Rn
^{210}Pb
continuous flux
Activity
$^{210}Pb_{ex}$
^{222}Rn
$^{210}Pb_{sp}$
^{226}Ra
Depth
Sediment flux
Hill slope
(source)
Activity
$^{210}Pb_{ex}$
$^{210}Pb_{sp}$
Depth
Pond
(sink)



137Cs
single pulse flux
Activity
137Cs
Hill slope
(source)
Depth
Sediment flux
Activity
137Cs
Depth
1963
Pond
(sink)
1957

Location: WGEW,
watersheds 201, 208, 214
Geology: alluvium
Elevation: 1250-1440 m
Rainfall: 270 mm y^{-1}



Vegetation:
whitethorn acacia,
creosote bush,
tarbush, black
grama, curly
mesquite

Watersheds and stock ponds

- Watershed drain into stock ponds excavated across drainage channels, separated by dam with spillway
- Sediment accumulation measured through periodic surveys of the surface when the ponds were dry.

- Continuous grazing
- Brush removal on watershed 201 (June, 1971), seeded to *Bouteioua curtipendula* and *gracilis*.

Watershed characteristics

Pond:	201	208	214
Constructed	1930s	1930s	1910s
Watershed area, ha	44	92.2	150.5
Channel slope	0.021	0.026	0.019
Precipitation, mm y^{-1}	277	269	277
Runoff, mm y^{-1}	11	13.4	16.8
Trap efficiency (Nichols, 2006)	0.91	0.76	0.92

Watersheds and stock ponds

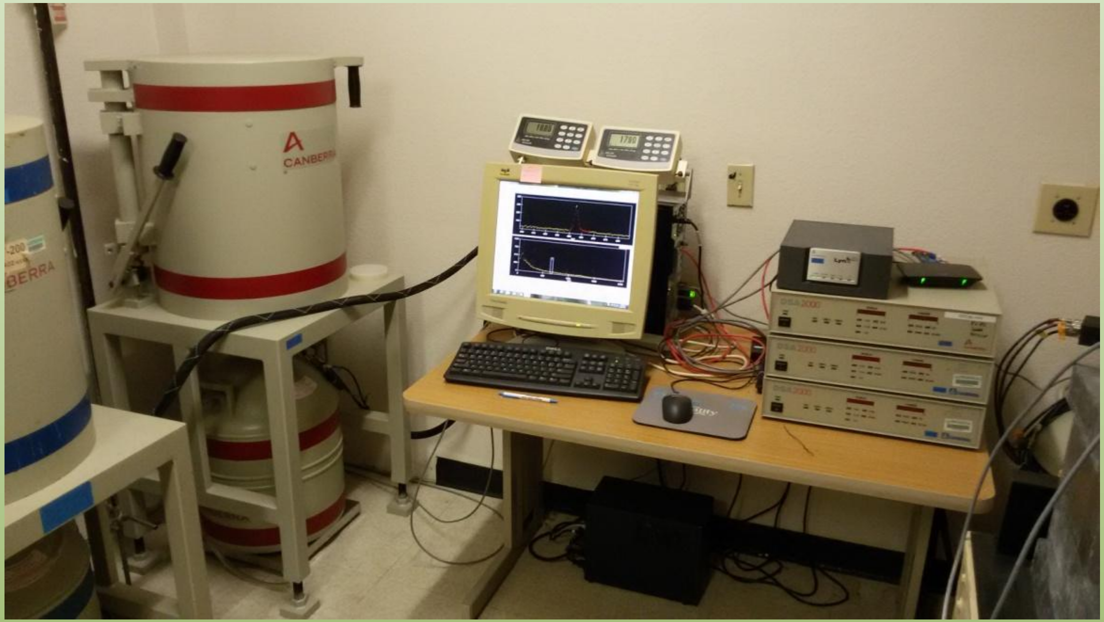
- Water level monitored using stilling well equipped with float and water level recorder
- Three automated rain gages in close proximity to ponds

Sampling and isotope analysis

- Profile samples were collected in May-July 2014 to the depth of 1.5 to 3 m at 15 cm depth increments.
- Profiles spaced 5 m apart in a cross sections across middle of the pond

Sampling and isotope analysis

- The samples ground, weighed, and incubated to establish ^{226}Ra – ^{210}Pb equilibrium.
- ^{137}Cs and ^{210}Pb activity was measured using gamma spectrometry system.
- Activity of ^{137}Cs and ^{210}Pb (total) - 661.6 keV and 46.7 keV photopeaks. Excess ^{210}Pb calculated through ^{214}Pb (351.9 keV).
- Activity measured to <5% uncertainty
- Corrected for self-attenuation (Quindos et al., 2006).

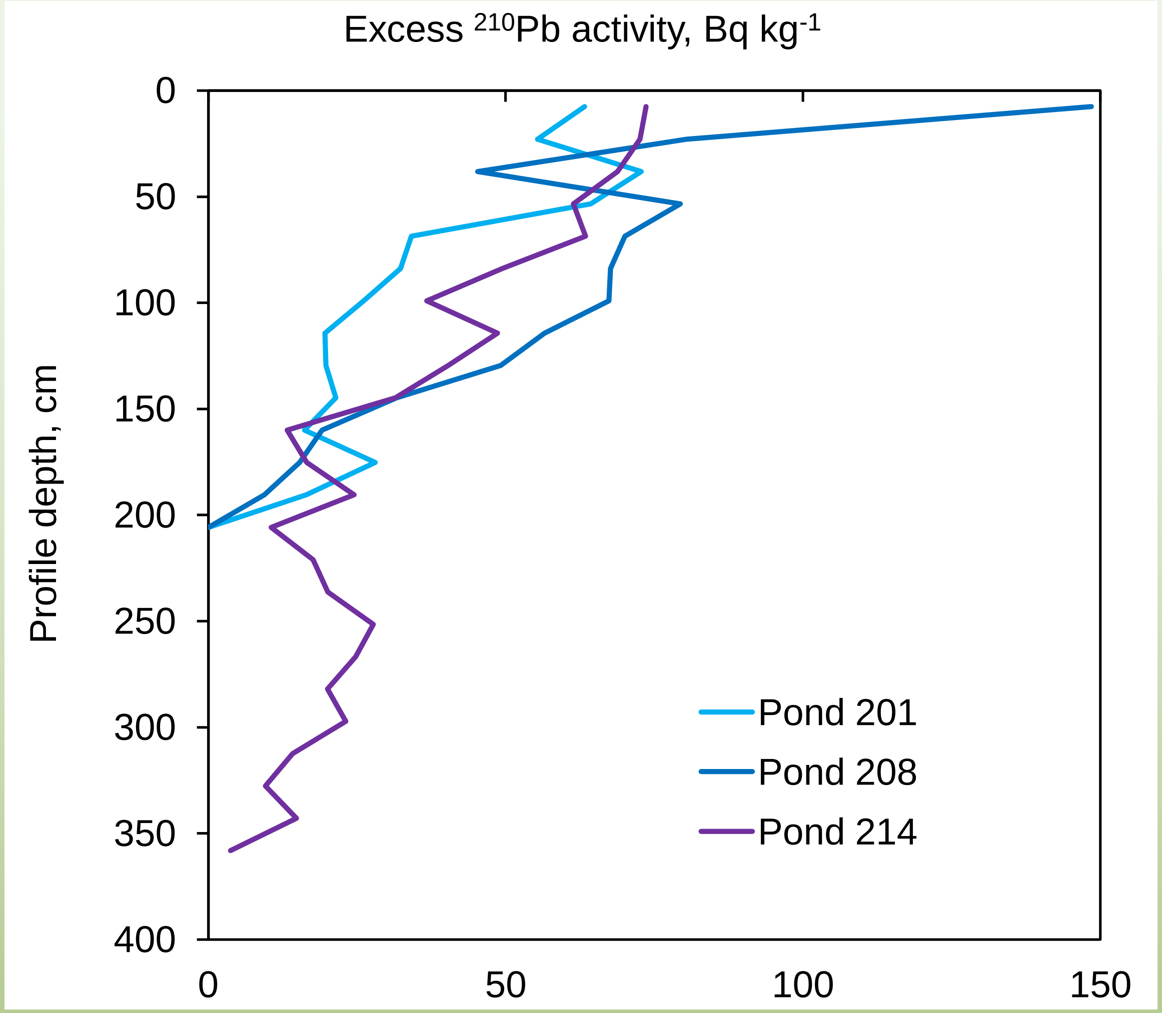


The CRS (constant rate of supply) model

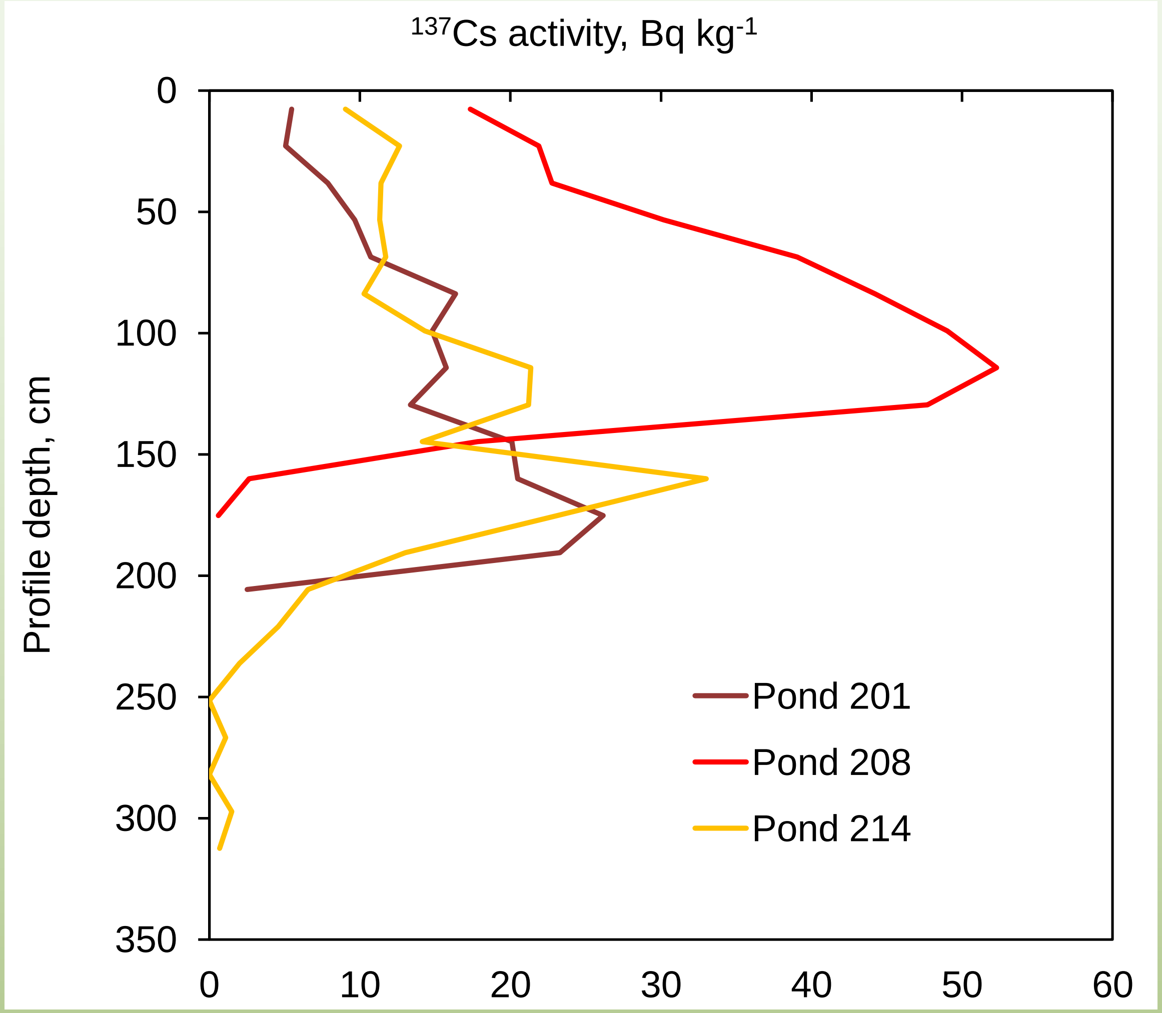
- The rate of deposition of $^{210}Pb_{ex}$ from atmosphere is constant
- $^{210}Pb_{ex}$ is quickly adsorbed to particulate matter
- The initial concentration in any sediment layer varies in inverse proportion to the sedimentation rate
- Non-monotonic variation of the $^{210}Pb_{ex}$ concentration versus depth
- The age of sediments at depth *i* :

$$t_i = \frac{1}{\lambda} \ln\left(\frac{A(0)}{A_i}\right)$$

where λ is radioactive decay constant (0.03114 y^{-1}), *A(0)* and A_i are unsupported ^{210}Pb inventories at depth *0* and *i*.



Distribution of $^{210}Pb_{ex}$ in sediments in the central (deepest) profile of the ponds.



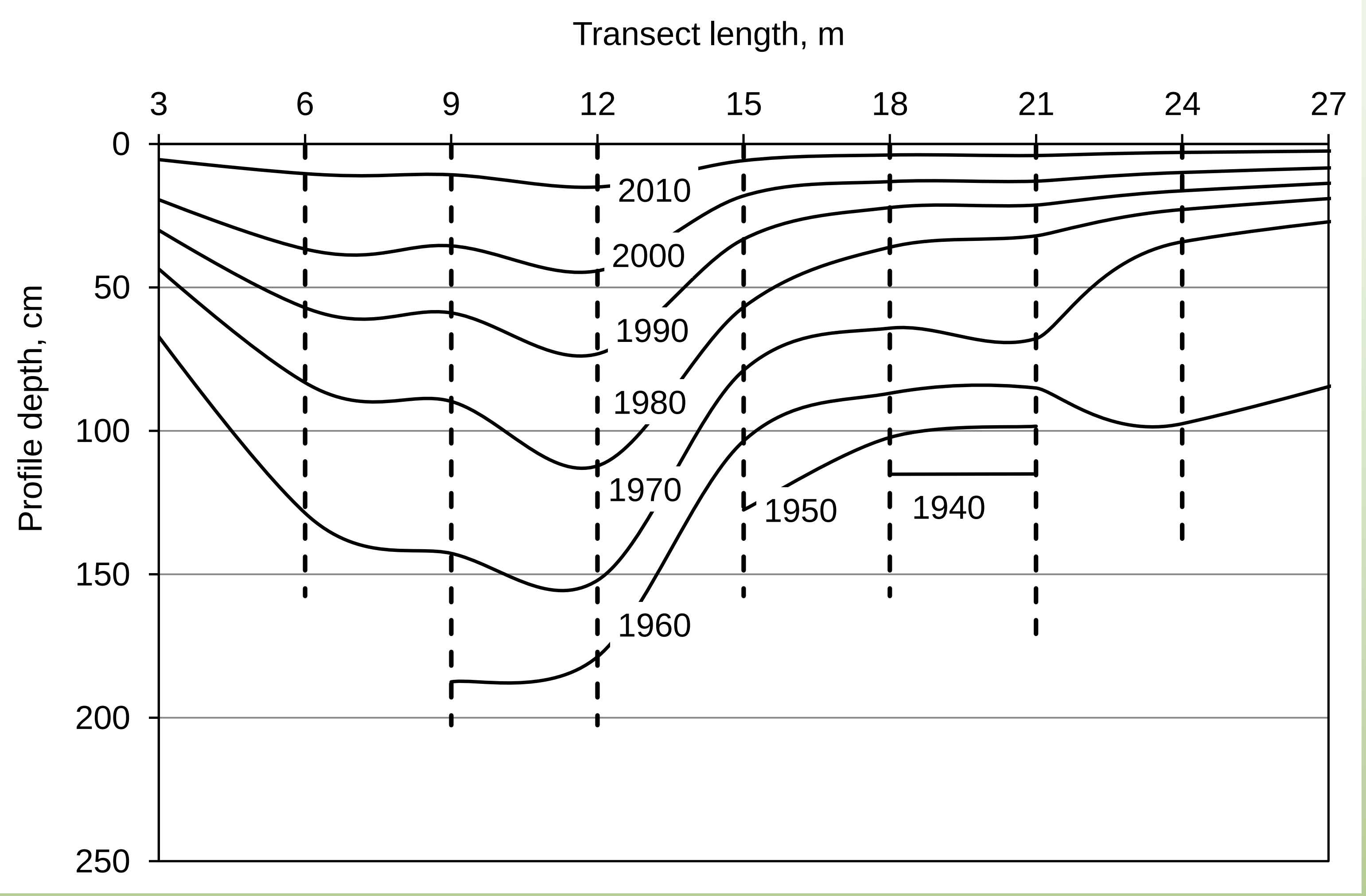
Distribution of ^{137}Cs in sediments in the central (deepest) profile of the ponds.

Results

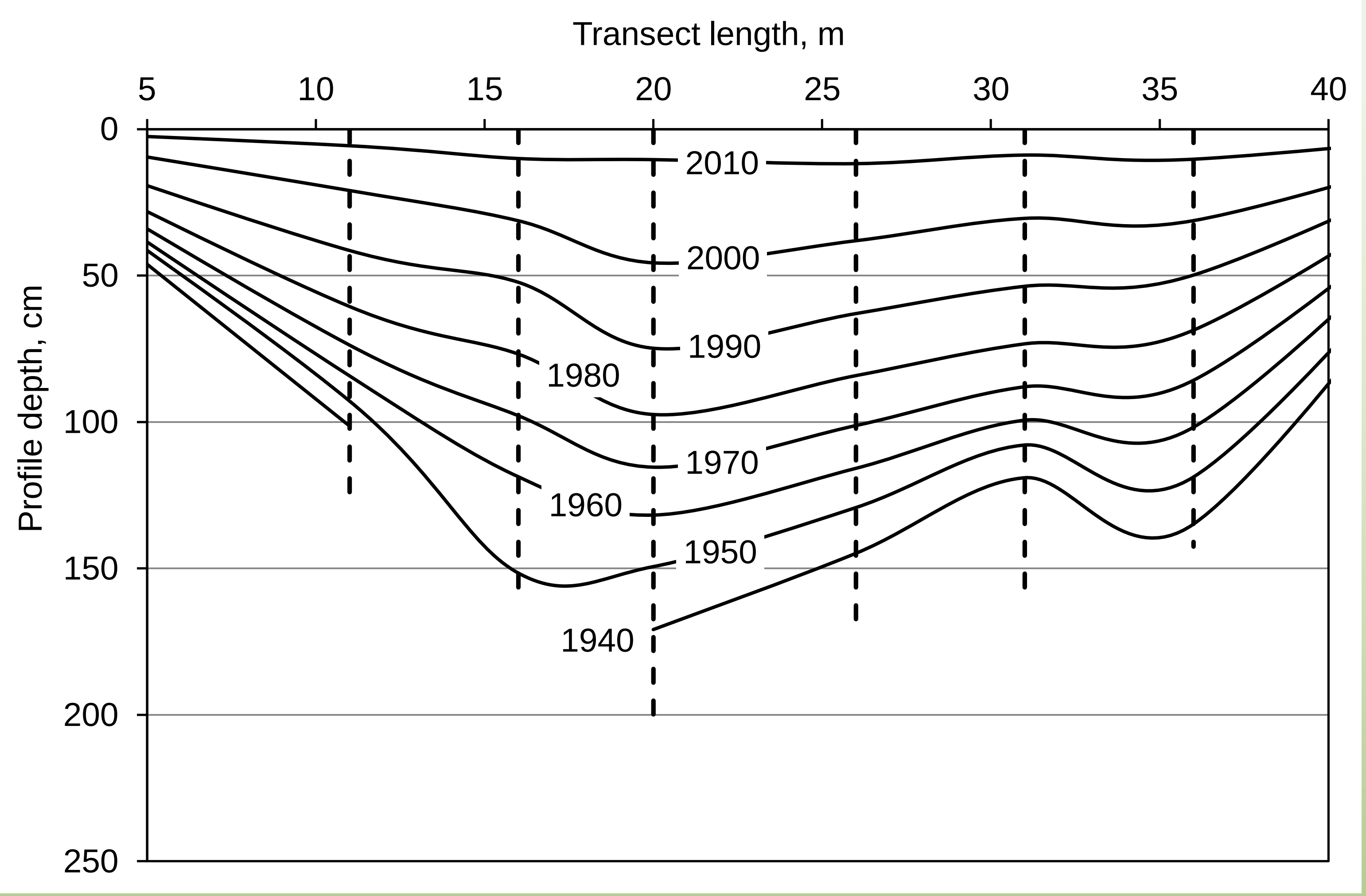
- Unsupported ^{210}Pb deviates from the exponential decay pattern
- Clearly identifiable ^{137}Cs peaks in all profiles at 125-175 cm corresponding to radiometric age of ~50 years
- Indication of physical or biological mixing
- Variable sedimentation rate causing dilution or concentration
- High activities - low accumulation rates, and vice versa.
- Non-monotonic ^{210}Pb concentration pattern - CRS model is appropriate

Estimated sediment accumulation and yield.

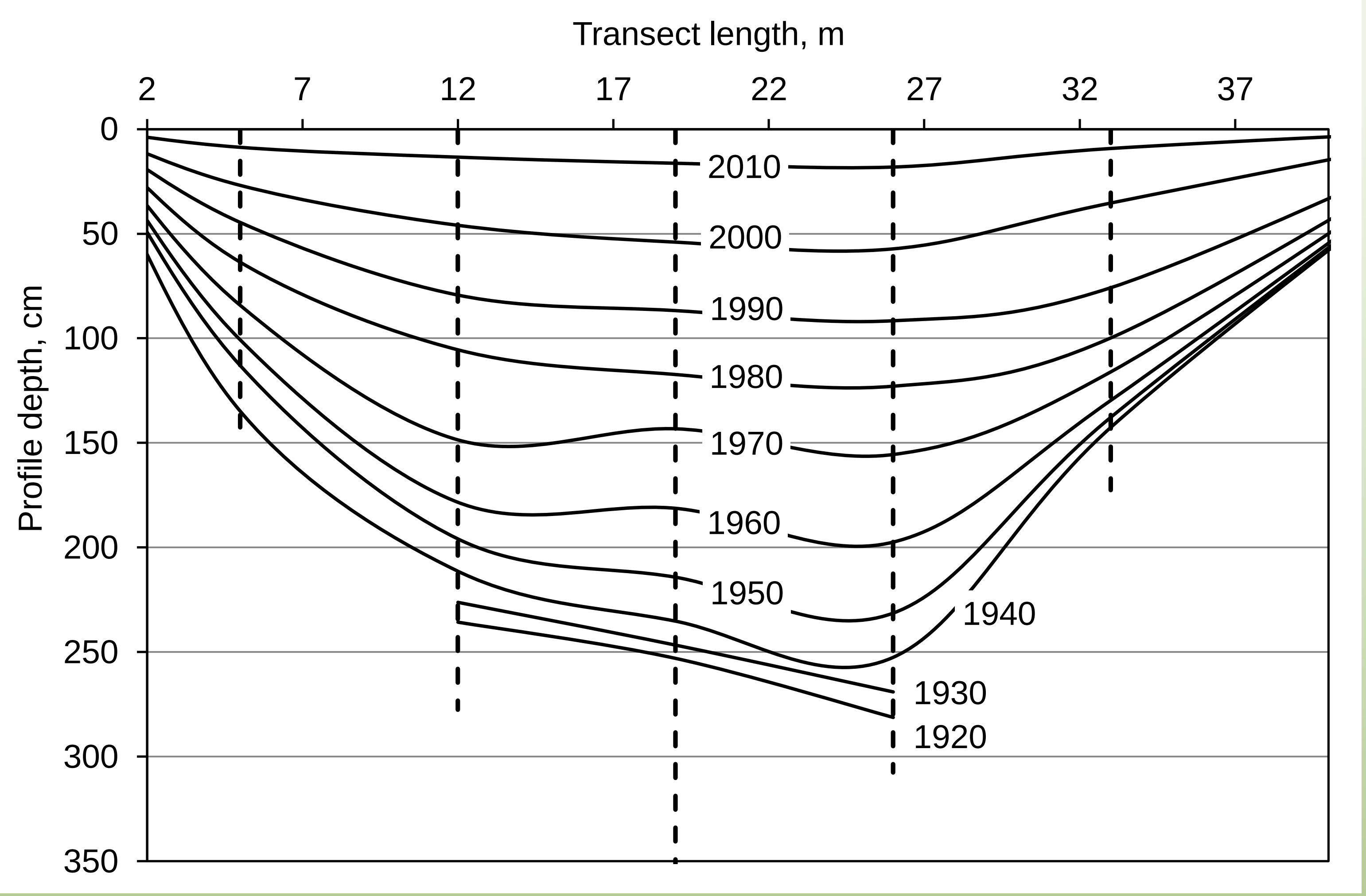
Pond ID:	201	208	214
Trapped sediment volume, m^3	2190	2470	20280
Sedimentation rate, cm y^{-1}			
average	2.1	1.9	2.3
max	3.8	2.4	3.3
min	1.1	1.3	0.8
Sediment yield, t ha^{-1} y^{-1}			
isotopes	0.8	0.5	2.0
survey (Nichols, 2006)	0.9	0.6	2.1



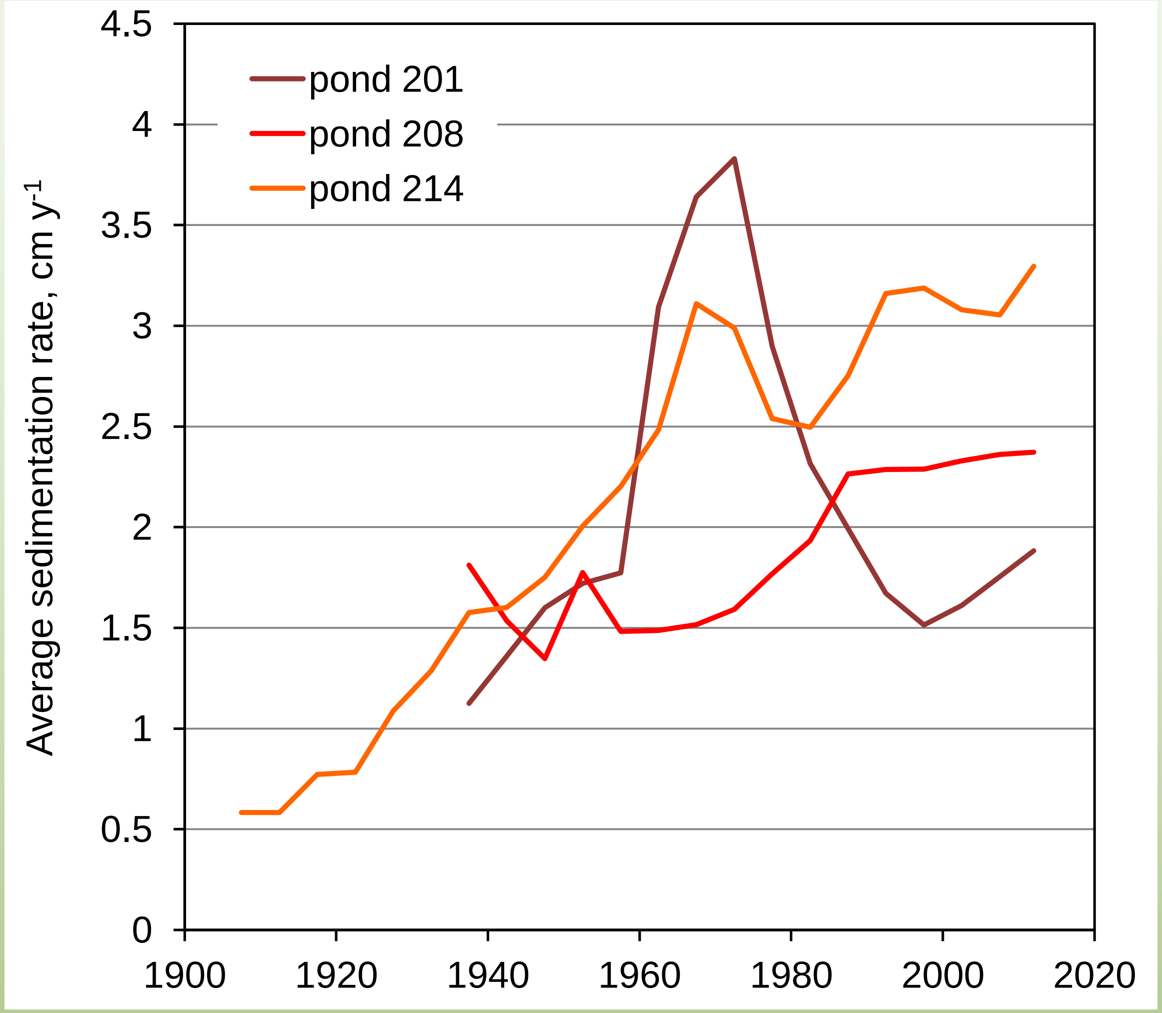
Sediment age along the transect in pond 201.



Sediment age along the transect in pond 208.



Sediment age along the transect in pond 214.



Sedimentation rate in ponds 201, 208, and 214 since construction.

Conclusions

- This is the first isotopic analysis of pond deposition backed by direct measurements of sedimentation.
- Estimated sediment yields (0.9 - 2.0 t ha^{-1} y^{-1}) were in good agreement with those measured via survey (Nichols, 2006) and obtained elsewhere on WGEW (Nearing et al., 2007).
- $^{210}Pb_{ex}$ distribution pattern was indicative of intermittent, flood driven depositional processes, where CRS applies.
- Due to the nature of accumulation in artificial ponds (incomplete profile) ^{210}Pb method requires a time marker for inventory correction. ^{137}Cs is a reliable tool for this purpose.
- Some management operations (mesquite removal, dredging) could be identified on the chronosequence.
- Overall ^{210}Pb technique can be a useful tool for estimation of erosion rates on small arid watersheds.
- There are over 28,000 stock ponds in Arizona alone - potential to study historic erosion processes on non-instrumented sites.