LONG-TERM SEDIMENT DYNAMICS AND PATTERNS OF CHANNEL EROSION IN A SEMIARID BASIN

Investigating the effects of spatial and temporal variability in rainfall

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Presented at the EGS XXVII General Assembly
24 April 2002, Nice, France

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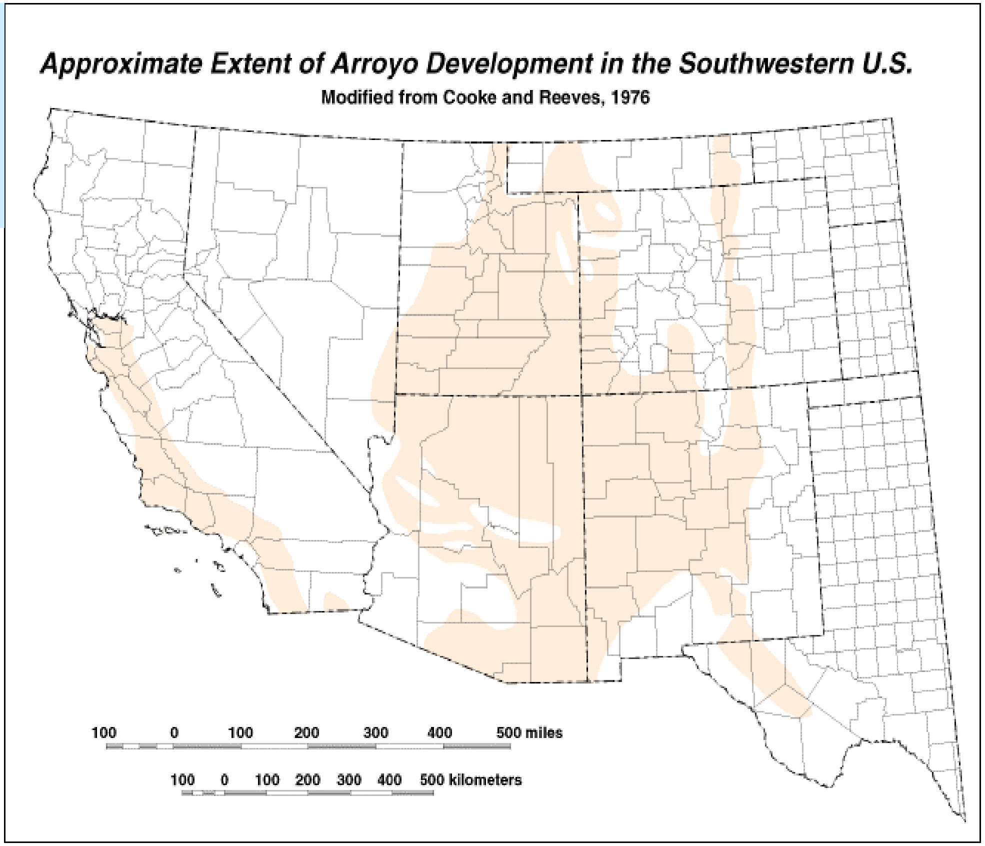
The Arroyo Problem in the US Southwest

SEDIMENT DYNAMICS
- cyclic behaviour
- rapid degradation (arroyo formation)
- slow aggradation



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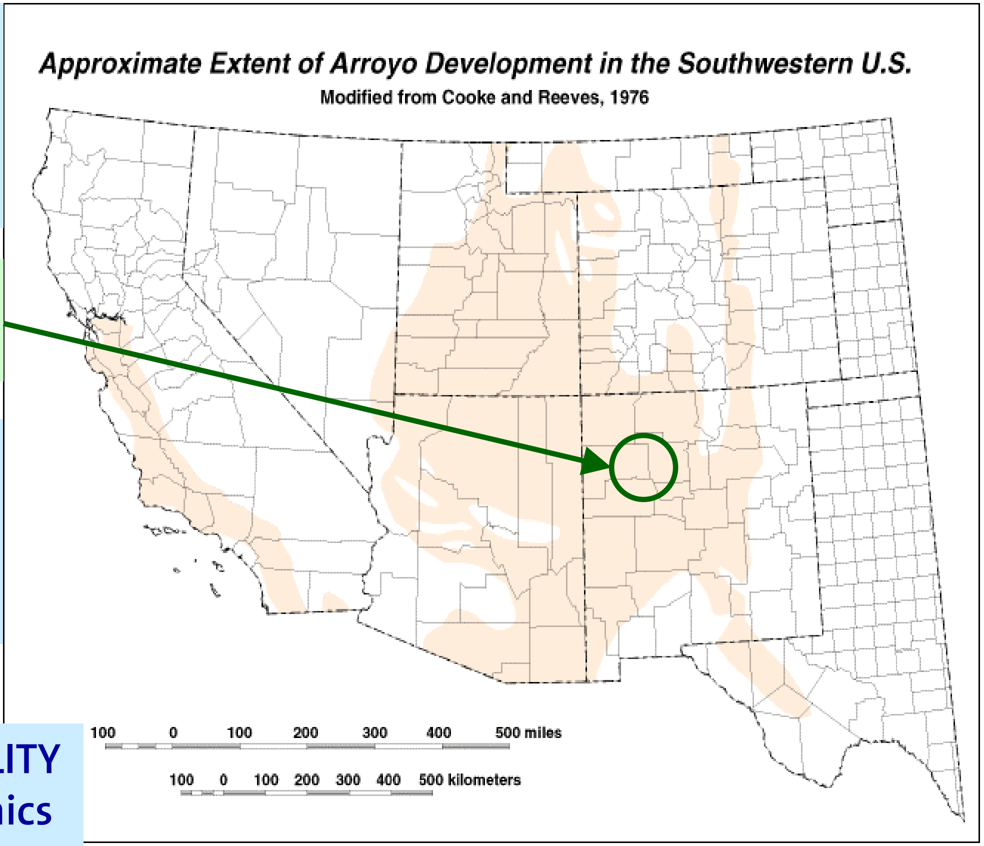
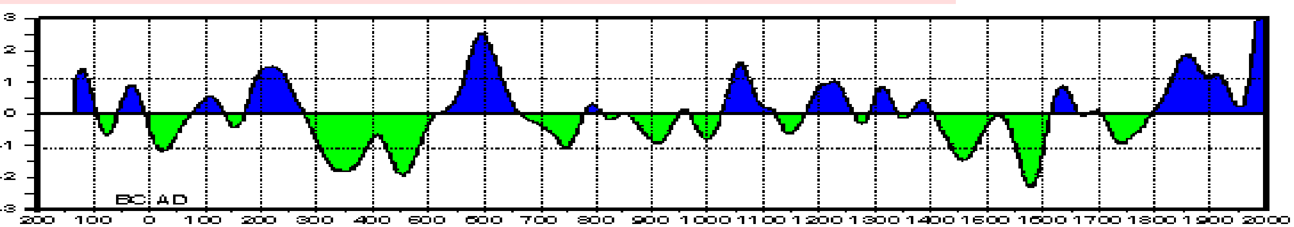
Rio Puerco Basin
(New Mexico)



Reasons for arroyo formation
- watershed changes
- precipitation changes
- intrinsic behaviour

LARGE SCALE CLIMATE VARIABILITY
dominates the sediment dynamics

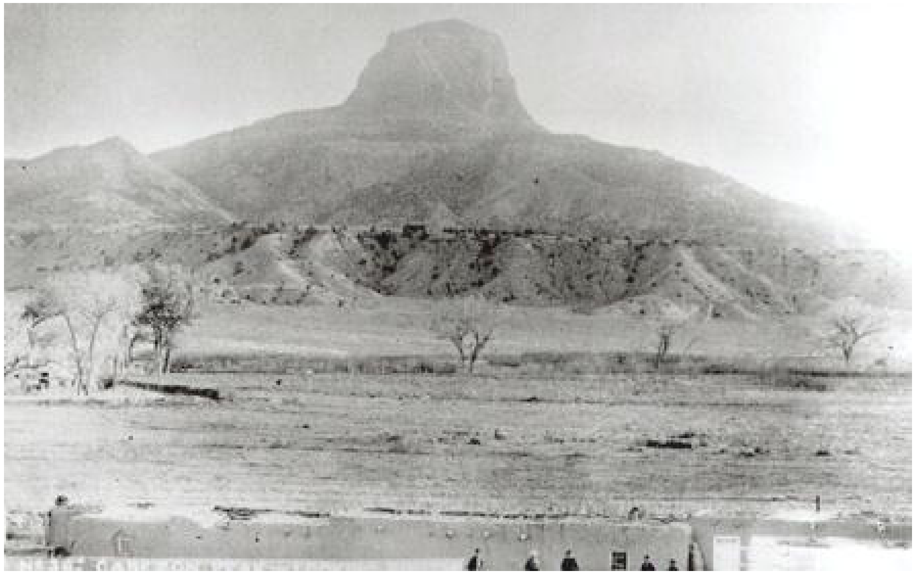
but, this relationship is not that simple



El Malpais National Monument (climate reconstruction), from *Grissino-Meyer* (1995)

Rapid erosion periods (*when and why?*)

Cabezon Peak near San Luis, Rio Puerco



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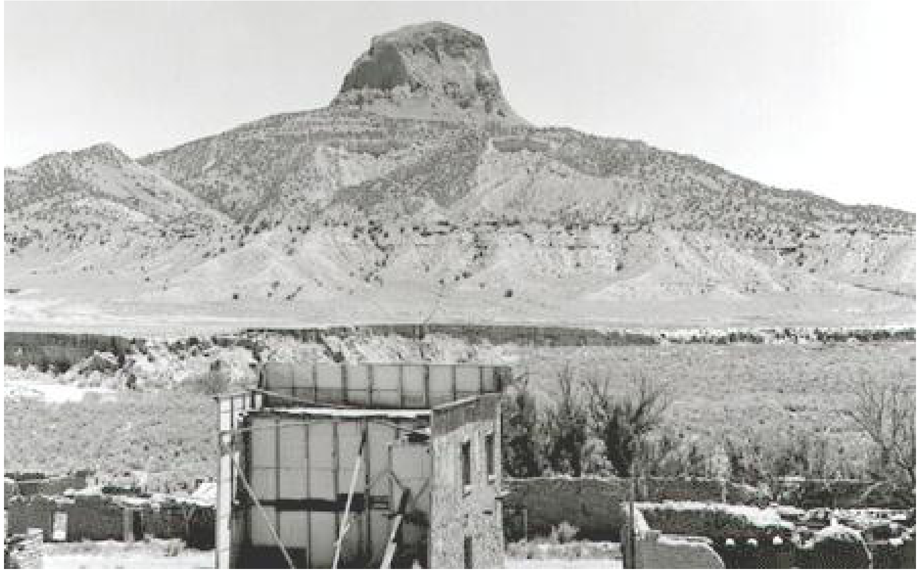

1977

Here we explore the propositions that...

- the *temporal variability* in rainfall governs the large scale channel dynamics
- the *spatial variability* in rainfall governs spatial patterns of erosion
- both of the above are connected with the *intrinsic basin rainfall-runoff response*
- *infiltration losses* strongly impact sediment dynamics

Modelling system (Molnar, 2001)

$$R(T) \xrightarrow{\text{RMS}} r(x, y, t) \xrightarrow{\text{RRM}} q(x_m, t) \xrightarrow{\text{ERMO}} e(x_m, y_m, t)$$

RMS
- seasonal linear disaggregation model
- temporal discrete random cascade model (d=1)
- spatial discrete random cascade model (d=2)

RRM
- conceptual linear reservoir model

ERMO
- flow and sediment transport model
- sediment balance model

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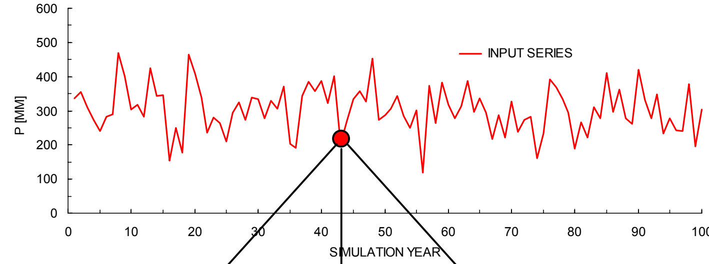
RMS



Annual rainfall

$\mathbf{R} = R(T)$

Seasonal rainfall (3 seasons)

$\mathbf{R} = \mathbf{A}\mathbf{R}_\mathbf{s} + \mathbf{B}\boldsymbol{\varepsilon}$

$R_1(t) \quad R_2(t) \quad R_3(t) \quad$ for $t = T$

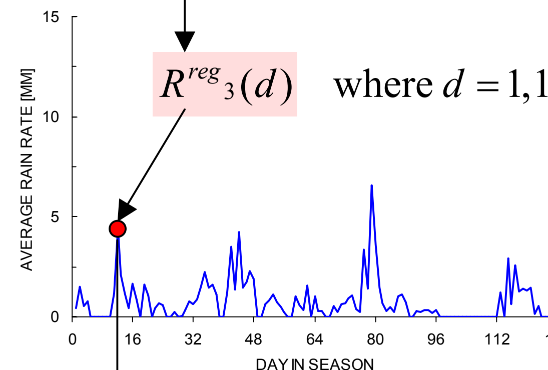
Daily regional rainfall (random cascade model d=1)

$\beta_t = f[R_i(t)]$

$\sigma_t = f(i)$

where $i =$ season

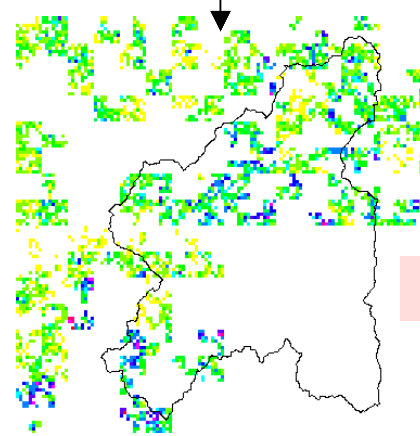
$R^{reg}{}_3(d)$ where $d = 1{,}128$



Daily spatial rainfall (random cascade model d=2)

$\beta_s = f[R^{reg}(d)]$

$\sigma_s =$ constant

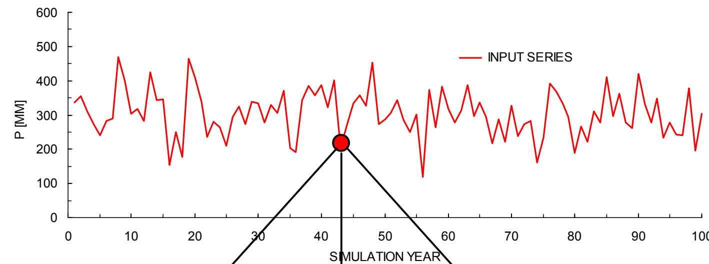


$r_s(d) = r(x, y, d)$

RMS

Annual rainfall

$$\mathbf{R} = R(T)$$



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$R_1(t)$ $R_2(t)$ $R_3(t)$ for $t = T$

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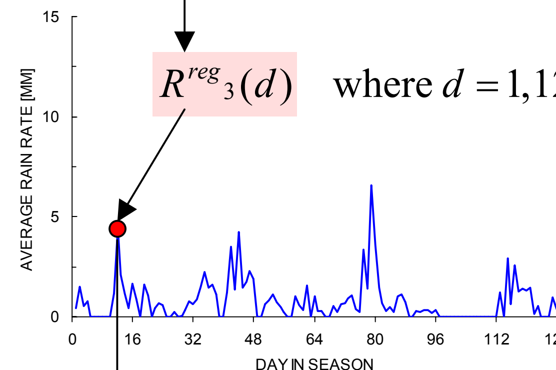

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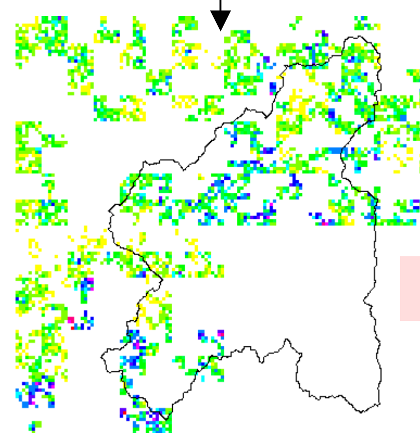
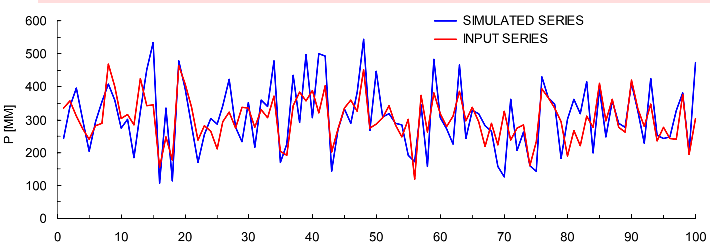


$$r_s(d) = r(x, y, d)$$

Model preserves
- volumes (at all scales)
- temporal and spatial scaling invariance



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ERMO (simple sediment balance model)

Water and sediment continuity

decoupled and solved with an explicit finite difference solution

$$\frac{\partial Q}{\partial x} + q_l - q_{\inf} = 0 \qquad q_{\inf} = f\,\overline{W}$$

$$W\frac{\partial q_b}{\partial x} + (1-p)W\frac{\partial z}{\partial t} = 0$$

Width adjustment

linear function of vertical channel change

$$W' = W + \Delta W \qquad \Delta W = -2h\,\Delta z$$

Sediment transport

transport limited bedload rating curve
(calibrated for the Rio Puerco)

$$q_b = \gamma\, q_s = a\,\gamma\, q^{\beta}$$

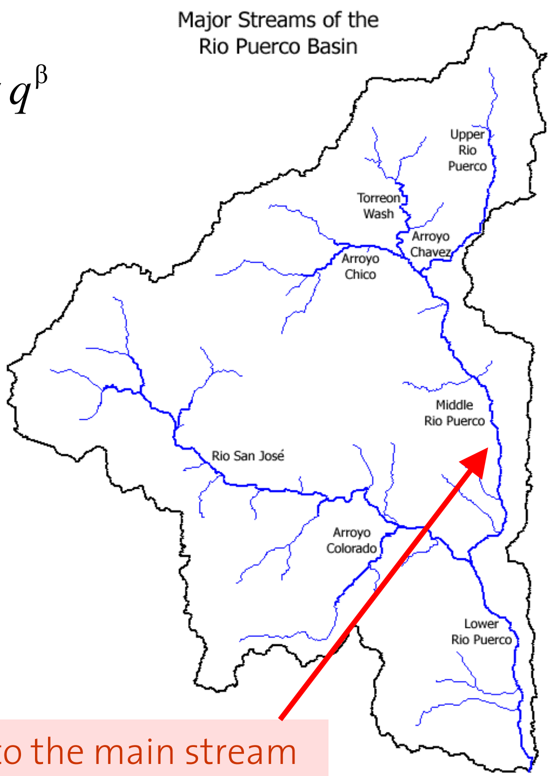
PARAMETERS (dimensionless)

- bedload parameter γ
- channel width change parameter h

PARAMETERS

- streambed infiltration rate parameter f (cm/hr)

(calibrated to satisfy the long-term average Rio Puerco Basin runoff)



applied to the main stream

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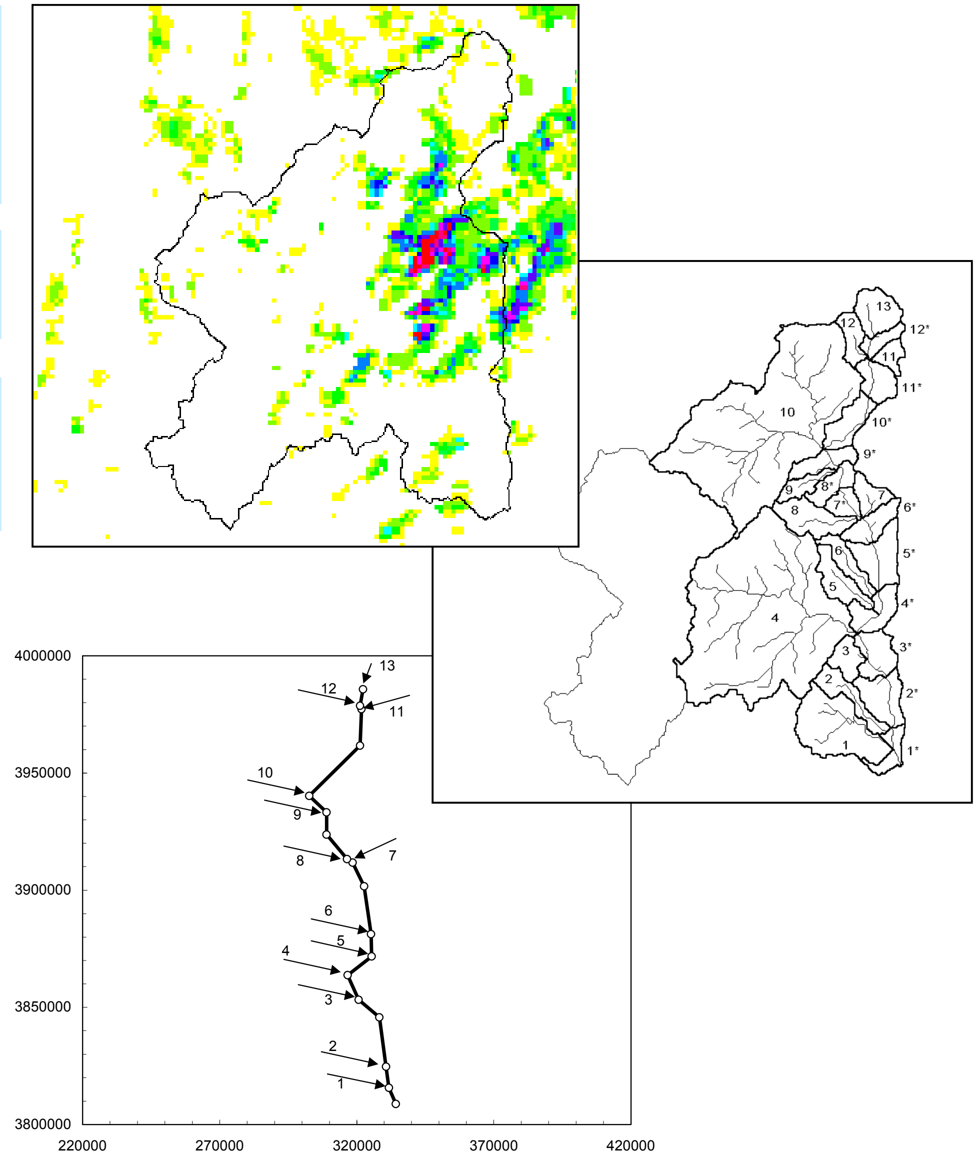

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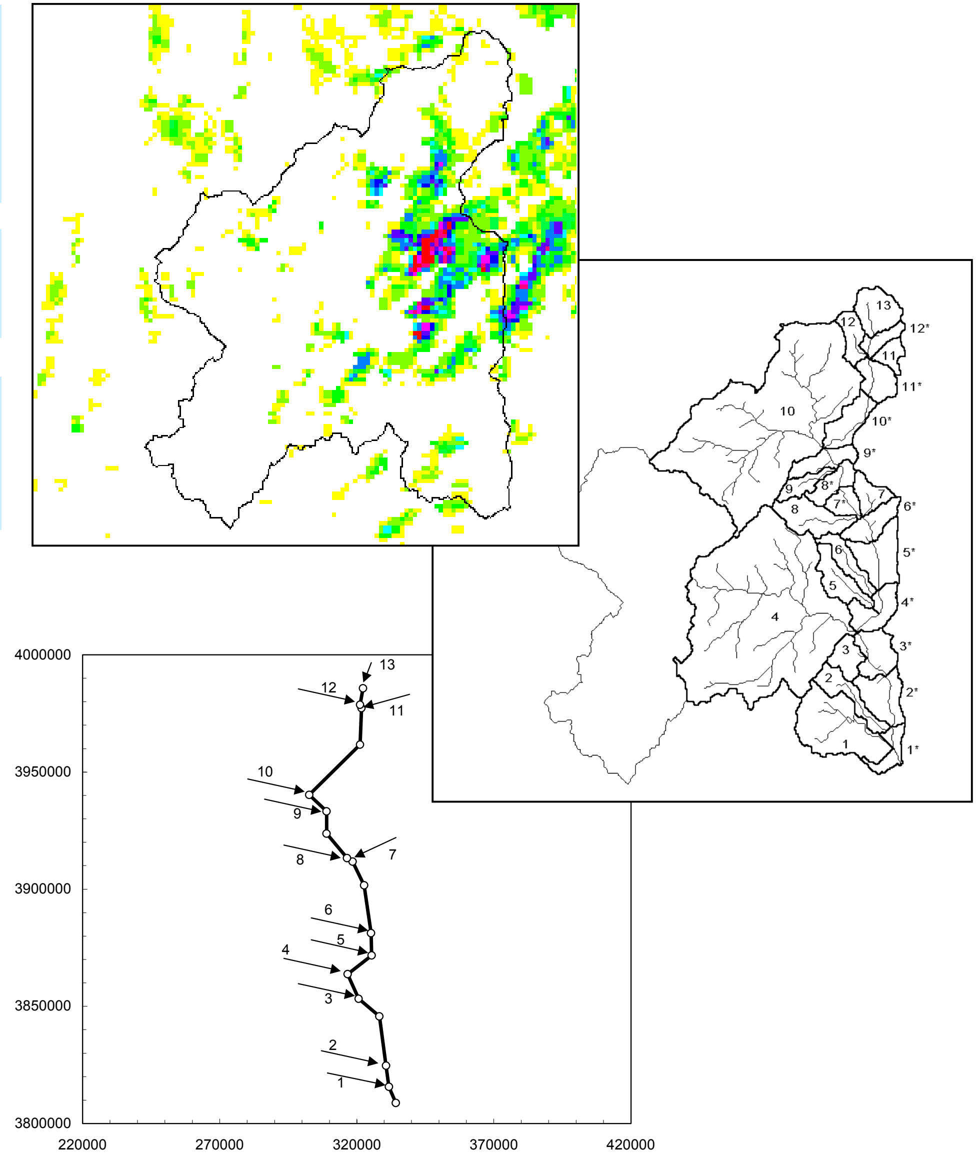


The MODELLING SYSTEM is set up to address 4 particular problems in semiarid river systems:

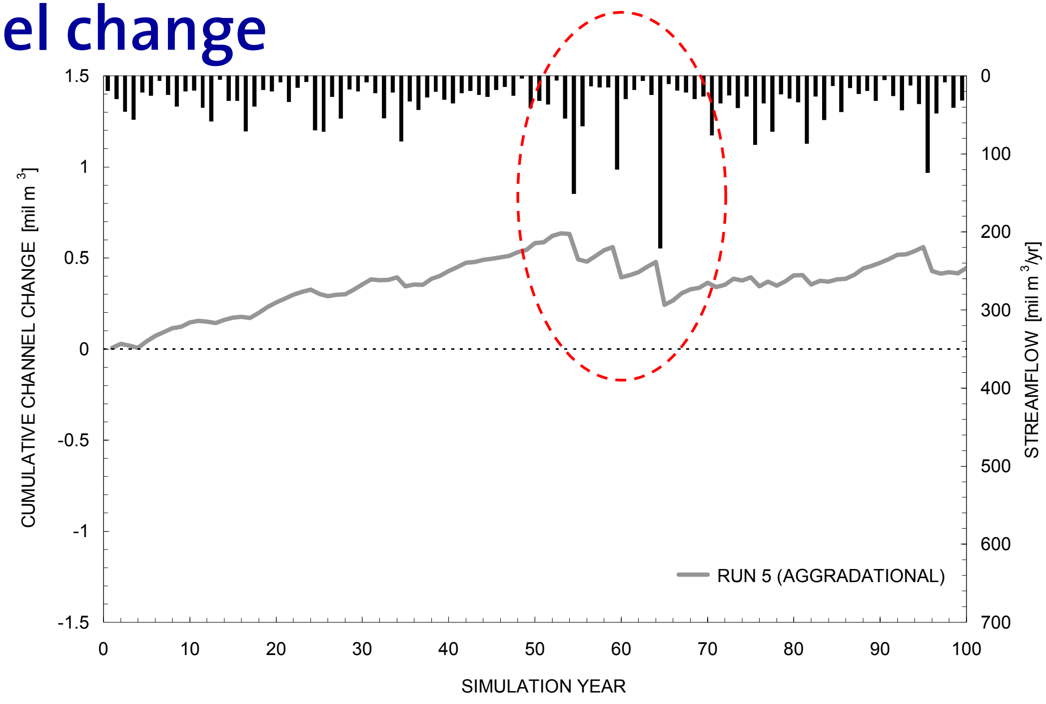
- *ephemeral* nature of streamflow
- *space-time variability* in rainfall
- *transmission losses* due to infiltration
- high *sediment load*

Temporal pattern of channel change

Current climate: P=280 mm
Example simulation

GENERAL BEHAVIOUR:

- *rapid degradation* in response to wet years with intense precipitation
- dominant and *gradual aggradation* in drier periods



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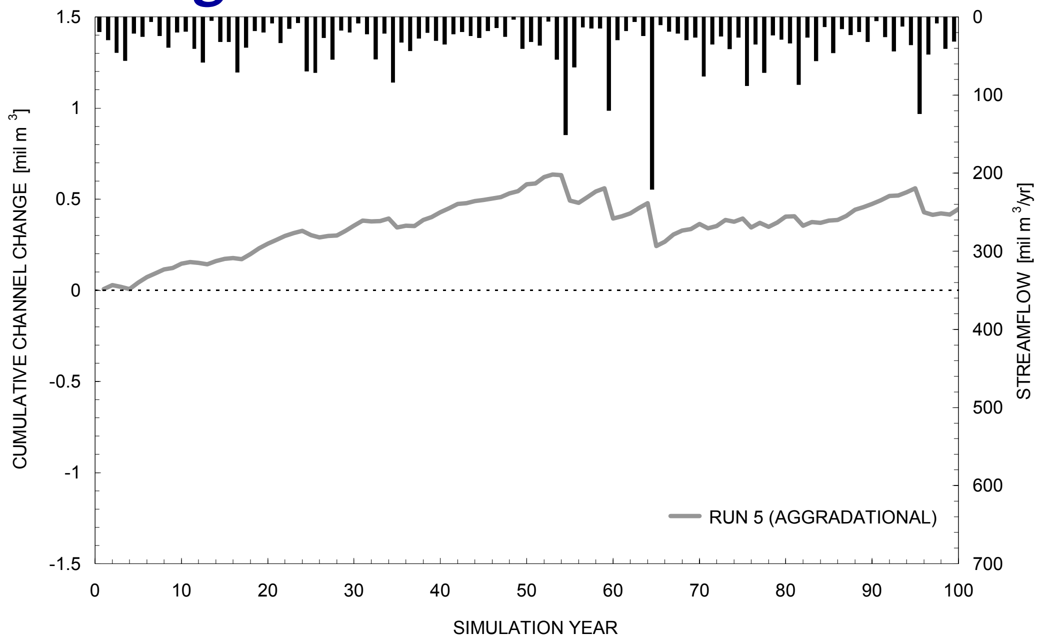
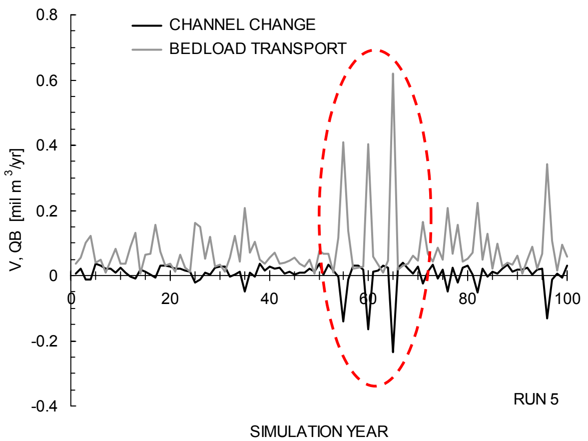


Channels as a source of bedload ?

in wet years over 30% of bedload can come from the channel



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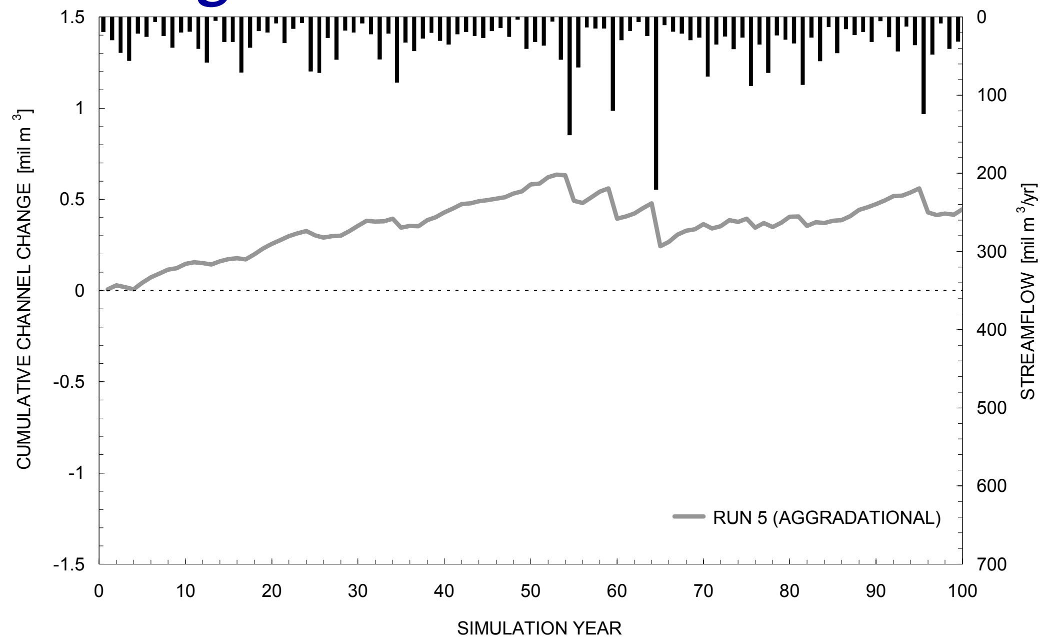

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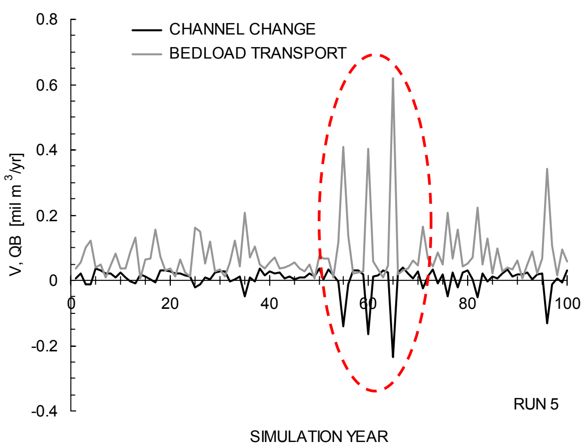
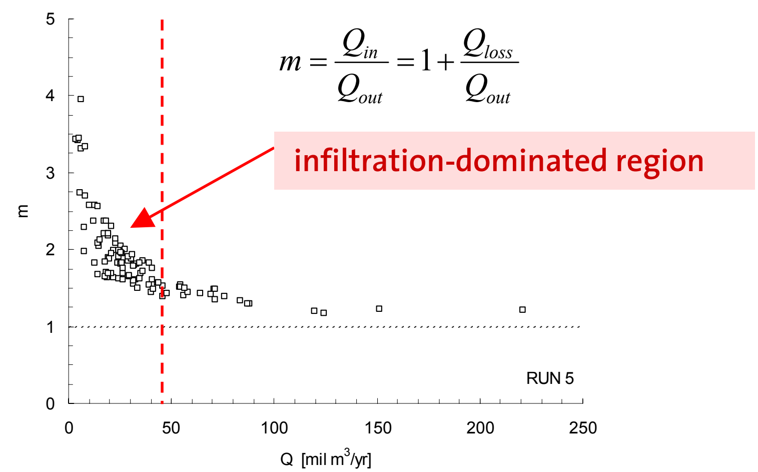


The role of transmission losses ?

In dry years over 50% of flow is lost in transmission



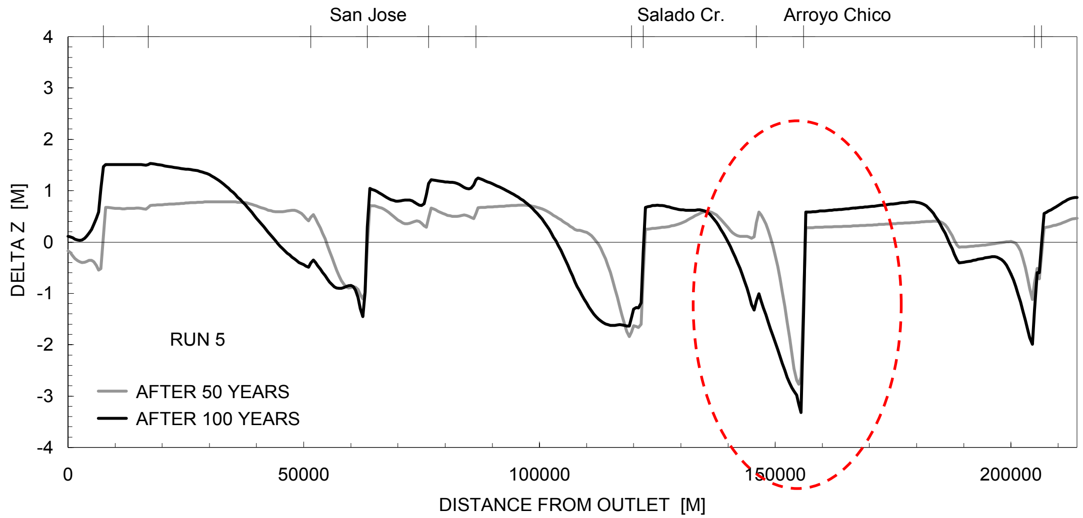
Spatial pattern of channel change

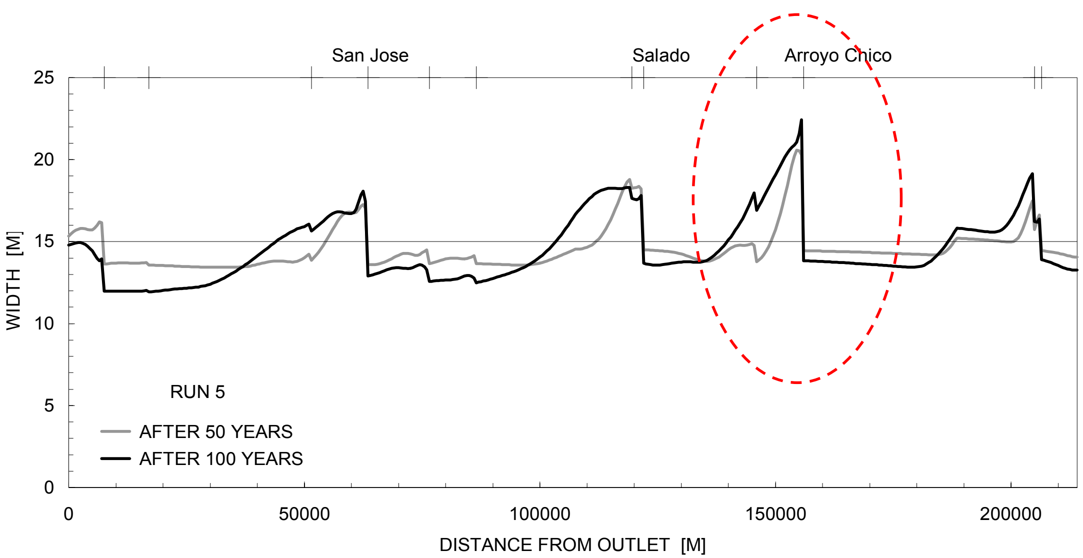
Channel change after 50 and 100 years in the Rio Puerco main stream

- max 3.8 m vertical erosion
- max 8.9 m channel widening

GENERAL BEHAVIOUR:

- *degradation* downstream of major tributaries
- *aggradation* in reaches with minor lateral inflow





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verification with data is difficult

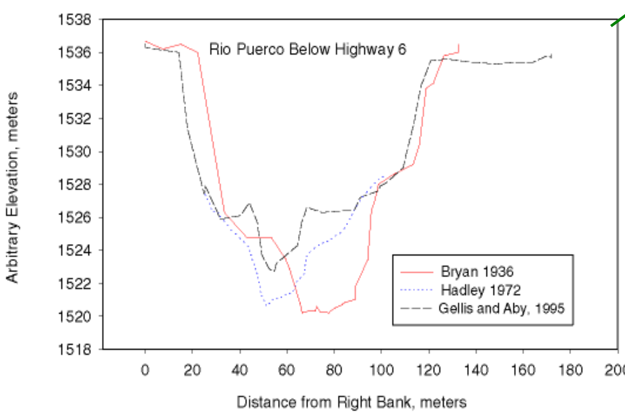
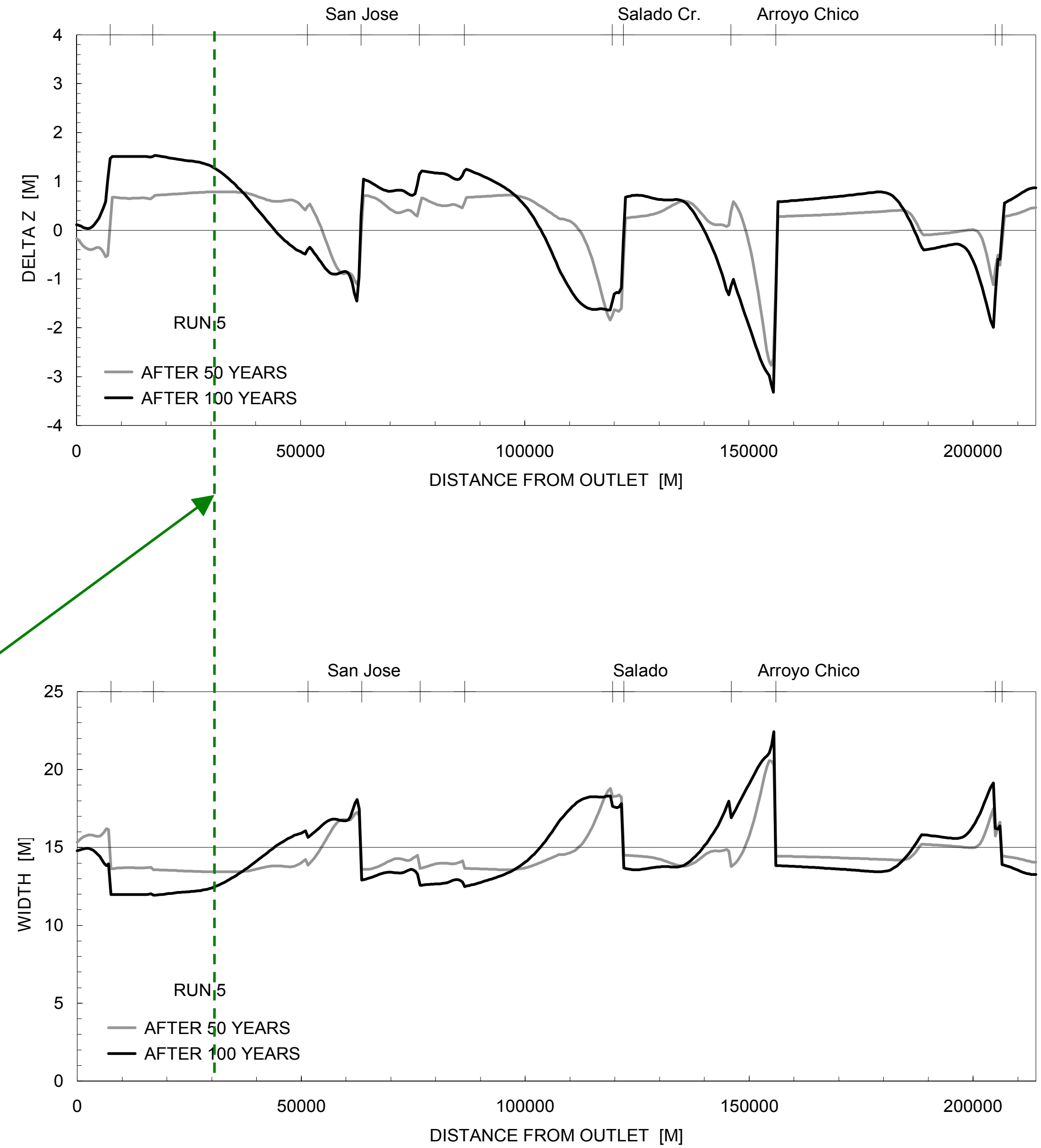


Figure 12. Replicate surveys of the Rio Puerco channel downstream of Highway 6.



Purpose ...

Analyse the space-time stochastic nature of channel change in semiarid basins

Ongoing work ...

Improvement of the erosion model
- extension to entire river network
- improvement of channel widening routine
- inclusion of variability in sediment load

Improvement of the precipitation analysis
- focus on the preservation of rainfall extrema
- inclusion of changing climate variability

MODEL VERIFICATION

- *Basin-wide surface erosion rates*
  - cosmogenic radionuclide dating: 1.6 million m^3/yr (0.1 mm/yr) [*Clapp & Bierman, University of Vermont*]
  - suspended sediment yield: 1.3 million m^3/yr
- *Point channel erosion and deposition rates*
  - tree-ring dating in trenches excavated in the Rio Puerco main stream [*Friedmann, USGS*]

Rio Puerco Online
http://climchange.cr.usgs.gov/rio_puerco/